EFFECTS OF DEFICIT IRRIGATION, FERTILIZATION, AND WETTING AGENT ON RUNOFF NUTRIENT CONCENTRATIONS AND EXPORTS FROM ST. AUGUSTINE LAWNS

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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May 2016

Major Subject: Soil Science

ABSTRACT

The need for water conservation and water quality preservation has become essential in the management of residential turfgrass through the United States as urban and suburban populations increase. In many urban areas, a considerable amount of water and fertilizers are used for lawn and landscaping needs, much of which may runoff and contribute to the degradation of receiving surface waters and turfgrass quality. This thesis examines runoff of DOC, DON, and PO_4-P concentrations and exports from fertilized and unfertilized simulated St. Augustine grass under deficit irrigation and fertilization or application of wetting agent. A strong and significant relationship ($p < 0.001$) was observed between DOC, DON, and PO_4-P exports and Na^+, K^+, Mg^{2+}, and Ca^{2+} exports during the first year of the study. The results suggest that in years with average rainfall, homeowners can maintain an aesthetic and functional St. Augustine turfgrass lawn and minimize nutrient exports in runoff by applying fertilizer twice a year and irrigating at a 30% ET_o rate. Due to limiting water supplies, expanding the use of wetting agents to residential lawns has become of interest. This study also investigated the effects of the application of a wetting agent on fertilized and unfertilized simulated lawns under deficit irrigation for 16 weeks. The application of wetting agent had no effect on the percent of retained water volume in the soil or the percent of water runoff after rain or forced irrigation events. More research is needed to determine whether wetting agents affect water retention and water runoff of residential lawns.

ACKNOWLEDGEMENTS

First, and most of all, I would like to express my deepest appreciation to my committee chair, Dr. Aitkenhead-Peterson, who was willing to take me as a research student. Without her support and counsel, this thesis would not have been possible.

I thank my committee members, Dr. Wherley and Dr. Munster, for their guidance and suggestions.

Thanks also go to Charles Fontanier, James Thomas, and Nina Stanley for their invaluable help at the field and in the lab.

Lastly, I would like to thank my parents, siblings and friends for their positive encouragement and support.

NOMENCLATURE

C	Carbon
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
DON	Dissolved organic nitrogen
EC	Electrical conductivity
EPA	Environment protection agency
ET	Evapotranspiration
HOA	Home owner association
N	Nitrogen
NIST	National Institute of Standard Technology
PAH	Poly aromatic hydrocarbon
PP	Particulate phosphorus
SAR	Sodium absorption ratio
SWR	Soil water repellency
TDN	Total Dissolved Nitrogen
TP	Total phosphorus
US	United States
WDPT	Water drop penetration time

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CHAPTER I

INTRODUCTION: LITERATURE REVIEW

The population of the United States is expected to increase by 98.1 million people by 2060. This is due mainly because of migratory flows from rural to urban areas, with a concomitant land use change to urban and suburban communities and their landscapes (Colby and Ortman 2015). These communities are expected to represent a significant portion of land cover in the form of green space, much of which serve a functional, recreational or aesthetic purpose. Urbanization refers to a "*rise in the proportion of a total population that is concentrated in urban settlements*" (Rogers 1982) including suburbanization with subdivision homes which results from the growth of a population and leads to an increase in the concomitant installation and establishment of turfgrass.

Many urban residents recognize that vegetation, such as trees, turf-grass and shrubs are necessary in urban areas in order to render them aesthetically pleasing; therefore turfgrass continues to dominate the urban and suburban landscape, commonly being used for lawns, recreational parks, sports grounds, and golf courses. Turfgrass covers an estimated 16 million ha in the United States, which is an area three times larger than irrigated corn and the single largest irrigated crop that does not contribute to food and fiber production (Milesi et al. 2005;Milesi et al. 2009). Specifically, urban residential, commercial, and institutional lawns account for 1.9% of the land coverage in the United States (Milesi et al. 2005) and it is increasing at an annual rate of 800,000 hectares (U.S. Dept. of Housing and Urban Development -2000).

Maintenance of turfgrass generally includes mowing and the management of clippings in the simplest form. With highly managed turfgrass there are the demands of fertilizer, herbicide, fungicide, and pesticide application and often the installation of in-ground irrigation systems in order to maintain an aesthetically pleasing lawn. The rates of fertilizer used by homeowners are close to those used for row crops and golf courses; 50% to 70% of homeowners throughout the United States apply fertilizer on a regular basis but do not base their applications on soil test recommendations (Barth 1995;Gu et al. 2015). The installation of turfgrass is widespread in urban and suburban ecosystems and the growing deposition of chemicals in residential lawns is a problem that is overlooked in terms of risks to surface water quality and as a result aquatic and human health (Robbins et al. 2001;Robbins and Sharp 2003). Whether lawns are a significant source of nutrients to urban surface waters is a frequently asked question by researchers.

1.1 Runoff in urban ecosystems

Stormwater runoff from urban grey space, those impervious surfaces such as roofs, roads, and parking lots, tend to be thoroughly investigated in terms of poly aromatic hydrocarbons (PAH) and metals (Brown and Peake 2006;Van Metre 2009). The urban grey space, specifically pavements for the most part act, as a link for runoff from urban green space to urban streams. Runoff from urban green space may also contribute significantly to water pollution (Cappiella and Brown 2001). In general, urban green space is encouraged as a means to reduce the volume of stormwater runoff from urban grey space.

Turfgrass is a dense, thick, and frequently thatch crop, which due to its nature, should decrease sediment loss, slow the velocity of runoff and allow more water to infiltrate the soil. Routing stormwater runoff from impervious surfaces onto pervious surfaces such as turfgrass may help mitigate increases in stormwater runoff volume caused by urbanization, by intercepting and infiltrating runoff (Mueller and Thompson 2009). For example, directing and draining water runoff towards landscaping and not the driveway will ensure that stormwater stays on the homeowner lot and allow it to infiltrate the soil. However, directing runoff to impervious driveways is a common homeowner management practice and thereafter runoff makes its way to the stormwater system and directly to surface waters. Homeowners may not realize that stormwater runoff may end up in surface waters but there are many ways of reducing its volume and improving the quality of stormwater runoff such as green roofs, filter strips, permeable paving, removal of downspouts, rain gardens, drainage swales, and retention or detention basins.

The condition of homeowner lawns and its management practices can have substantial impact on the quality and quantity of urban runoff (Milesi et al. 2009). Runoff quality and quantity from urban and suburban lawns varies according to individual homeowners management practices such as fertilizer application, decomposition of clippings, chemical content of irrigation water, thatch density, and soil water storage (Barth 1995;Steele and Aitkenhead-Peterson 2012). In addition, it should be noted that dry and wet deposition of atmospheric N can by quite considerable in some regions which is often responsible for increased aquatic N rather than the assumed over-fertilization of urban green-space (Jaworski et al. 1997). Runoff from urban green-space can carry pesticides, herbicides, and nitrogen fertilizers that pollute the water supplies into which they drain (Jenkins 2015).

Undesirable environmental and economic consequences can result from the presence of excess nitrogen and phosphorus in surface waters. Rice and Horgan (2011) examined nitrogen and phosphorus in runoff from a highly managed creeping bentgrass (*Agrostis stolonifera)* managed as a golf course fairway. Their turfgrass was cut 3 times each week and the clippings removed. Fertilizer and pesticides were applied according to manufacturers' directions and simulated rainfall was applied between 13 and 39 h after fertilizer and pesticide application. They reported that all runoff water N was below concentrations associated with eutrophication (1 mg L^{-1}) and three orders of magnitude below the EPA NO_3-N standard for drinking water quality (10 mg L^{-1}).

1.2 Irrigation of urban green space

Loss of water through runoff and the concomitant transport of nutrients from urban lawns has been receiving increased scrutiny in recent years due to increasingly limited water supplies and environmental damage associated with lost from terrestrial to aquatic ecosystems (Hipp et al. 1993;Erickson et al. 2001). In order to maintain aesthetically pleasing turfgrass, lawns require 25.4 mm (1 in.) of water a week, and so a 7.62 x 12.2 m (25 x 40 ft.) lawn would require thirty seven thousand liters of water each summer (Wilson 1961). Residential water use for outdoor purposes in North American cities has been estimated to range from 22-38% in cool climates and 59-67% in hot and dry climates, making up to 75% in arid and semi-arid environments (Mayer et al. 1999;Milesi et al. 2009).

In the southeastern United States, landscape irrigation accounts for two thirds of summer time and more than half of annual residential water use (Mayer et al. 1999). Urban landscapes can consume prodigious amounts of water, particularly during summer months, where 40-60% of residential water consumption is used for the irrigation of landscapes (White et al. 2004). Much of the water used for urban irrigation comes from municipal sources, which originate from rivers, lakes, reservoirs, groundwater or a blend of these sources and thus the quality can vary significantly (Azoulay et al. 2001;Steele and Aitkenhead-Peterson 2012). For example, in the state of Texas, the concentration of sodium in municipal tap water varies from 8 mg L^{-1} to 250 mg L^{-1} in cities throughout the state which may impact soil solution water chemistry and extractable losses of carbon, nitrogen, and phosphorus (Steele and Aitkenhead-Peterson 2012).

1.3 Deficit irrigation of urban green space

Because of increasingly limited water supplies, especially in areas with frequent drought conditions, the concept of deficit irrigation has been examined. Tayfur et al. (1995) suggested that: a) reducing irrigation run times and consequently the volume of water being applied, b) increasing the amount of time in between irrigation events, and c) decreasing irrigation amounts when the plants are not in growing season would decrease the volume of outdoor water use. The volume of irrigation water to use is often measured as evapotranspiration (ET), which is the volume of water lost through transpiration from the shoots and the water evaporated from the soil surface (Schiavon et al. 2014b). The Penman-Monteith equation is the most advanced model for estimating ET rates for a well-watered reference surface based on solar radiation, temperature, wind speed, and relative humidity; it is an estimate of the water demand for an idealized crop and is commonly referred to as reference ET (ET_o) (Allen et al. 1998). Based on ET_o, an irrigation schedule can be adjusted to the volume of water required for a well-watered crop (Allen et al. 1998). Conversely, deficit irrigation provides less water than the maximum evapotranspiration (Feldhake et al. 1984). Research has shown that most turf grasses can sustain functionality and quality even at irrigation levels below their ET_o and this management practice can be used as a successful water conservation strategy (Shearman 2008;Schiavon et al. 2014b, a).

1.4 Effect of urban runoff on surface water quality

Surface water quality standards are provisioned by states, territories, and authorized tribes but ultimately need approval by the EPA to protect or change the desired condition of a surface water (Environmental Protection Agency 1994). About 1.3 million acres of lake in the United States are impaired by nutrients from urban runoff and storm sewers (Environmental Protection Agency 1994). Improper irrigation practices such as over-irrigation and large rainfall events can result in runoff from urban landscapes which has the potential to carry inorganic compounds such as NO_3-N, NH_4-

N, PO_4-P, and organic compounds such as dissolved organic nitrogen (DON) and dissolved organic carbon (DOC), and sediment into local streams and lakes where they may contribute to eutrophication or over-enrichment (Barth 1995).

Cultural eutrophication is a result of an over enrichment of P and N (Schindler et al. 2008). In the 1970's many researchers also theorized that cultural eutrophication was also caused by C but after several in vitro experiments this was shown not to be true (Schindler 1977). In terms of excess N and P, the limiting element for cultural eutrophication of lentic waters is generally P; if P in this surface water is plentiful phytoplankton can utilize the N present, or in the absence of N, the community composition of phytoplankton will shift to one that is capable of fixing gaseous N from the atmosphere (Schindler 1977). Rice and Horgan (2011) suggested that concentrations of 0.025 mg L^{-1} soluble reactive phosphorus would increase algal growth and eutrophication of reservoirs and lakes and 0.05 mg L^{-1} would cause eutrophication in streams draining into reservoirs and lakes based on established water quality criteria. They further suggested that a concentration of >1 mg L^{-1} nitrogen would increase algal growth (Rice and Horgan 2011).

1.5 Nitrogen

1.5.1 Inorganic nitrogen

The terrestrial, aquatic, and atmospheric nitrogen cycle has been greatly altered by anthropogenic activities by accelerating the rate of N fixation and delivery of N to water bodies (Boyer et al. 2002). Dissolved inorganic nitrogen, specifically NO_3-N which is a conservative ion, is a readily leached or lost as runoff from ecosystems if not taken up by plants because it does not adsorp well to soil minerals (Nodvin et al. 1986). Pellerin et al. (2004) reported that inorganic nitrogen concentrations were two orders of magnitude higher in urban and highly developed areas when compared to less developed or forested watersheds. Wahl et al. (1997) investigated the effects of urbanization on steam nutrient loading from an urbanized and a forested watershed and reported that DIN derived from the urbanized watershed was double the DIN derived from the forested watershed (34 vs 14 kg N yr^{-1} respectively). These inorganic nitrogen inputs strongly correlate with populated regions. For example, a study in New England, studied the impact of urbanization and agriculture on DIN concentrations from the Charles River basin which had 22.2% land use classified as urban, 59.3% classified as forested, and 8.4% classified as agricultural yet had 1756 kg N km^{-2} yr^{-1} exported as DIN, mostly due to permitted wastewater discharge (Boyer et al. 2002). The higher concentration of DIN from urban environments may be the result of less opportunity for the recycling and removal of inorganic nitrogen such as that being taken up by microbial and vegetative processes that typically occur naturally in a forested watershed (Wahl et al. 1997). Limited research is available for the losses of inorganic nitrogen specifically from home lawns. A 2 year research conducted at Rhode Island on Kentucky bluegrass turf plots with 2-3% slope were subjected to three levels of fertilization and two irrigation regimes using orifice flow splitters. They found an annual loss of inorganic N ranging from 32 kg ha^{-1} to 2 kg ha^{-1} yet losses from fertilizer comprised <7% of total waterborne loss of inorganic N from any treatment (Morton et al. 1988).

Nitrate is easily leached into groundwater and streams because it is the most mobile and soluble form of inorganic nitrogen (Valiela et al. 1990). The loading of nitrate in surface waters causes increased growth of microalgae and phytoplankton, reduction of seagrass beds, and reductions in fauna (Ryther and Dunstan 1971). Since 1985, eutrophication has emerged as a major problem in Chesapeake Bay, the largest estuary in the United States (Howarth et al. 1996). Increased concentrations of inorganic nitrogen during the past few decades is responsible for the increased phytoplankton primary production for algal blooms causing the large-scale eutrophication of the Baltic Sea (Wulff et al. 1990). Nitrate concentrations have increased during the past 100 years in streams that drain some parts of the Mississippi Basin and concentrations have nearly tripled in the Gulf of Mexico (Howarth et al. 1996). This increase of nitrate increases the production of organic carbon through increased photosynthesis and can in turn lead to hypoxia which occurs when dissolved oxygen concentrations are less than 2 mg L^{-1}, due to stress or death in aquatic organisms (Goolsby 2000). Nitrate also contributes to the acidification of surface waters in urban watersheds (Henriksen and Brakke 1988).

Much less is published on NH_4-N exports from urban ecosystems. Unlike NO_3-N, NH_4-N binds well to soil and is not so easily lost to aquatic ecosystems. In general, high concentrations of NH_4-N in surface waters are due to untreated sewage in developing countries (Bhatt and McDowell 2007).

1.5.2 Dissolved organic nitrogen

Dissolved organic nitrogen (DON) is a mobile organic form of nitrogen which comprises a mixture of compounds such as urea, free amino acids, amino sugars, humic acids, proteins, peptides; and therefore may play an important role in plant nutrition and nitrogen flux (Bronk 1997). DON is found in almost every terrestrial and aquatic ecosystem and in urban ecosystems. DON exports reflect the loss of terrestrial organic nitrogen to surface waters from rapidly expanding urban ecosystems. The proportion of DON of total N export from urban ecosystems tends to be much smaller compared to that observed in undisturbed watersheds (Pellerin et al. 2004;Aitkenhead-Peterson et al. 2009). DON may constitute a significant component of total dissolved nitrogen (TDN) typically representing 40-50% of the total N in streams and lakes but may also represent greater than 85% of the TDN in undisturbed watersheds (Willett et al. 2004).

Although there is awareness of nitrogen loss as DON, few studies have examined DON concentrations in, and exports from urban ecosystems (Petrone 2010;Steele and Aitkenhead-Peterson 2012;Wherley 2015;Aitkenhead-Peterson 2016). Aitkenhead-Peterson and Steele (2016) examined DON exports in the upper Trinity River, upstream and downstream of the Dallas/Fort Worth metropolis and reported that DON exports were an order of magnitude higher downstream of Dallas/Fort Worth when compared to upstream exports. Petrone (2010) reported DON exports in catchments of the Swan-Canning River system in south Western Australia. DON exports ranged from 18 to 42 kg km^{-2}-yr^{1} from watersheds with 7% and 42% urban land use. These exports were much lower than those reported by Aitkenhead-Peterson and Steele (2016) at a comparable urban land use cover (11 and 57%; DON exports 27 - 179 $km^{-2}yr^{-1}$). These differences may be due to differences in the amount of precipitation and therefore runoff because DON concentrations tended to be lower in the upper Trinity River (0.31 - 0.33 mg L^{-1}) relative to catchments of the Swan-Canning River system (0.31 - 0.60 mg L^{-1}) but annual precipitation was higher (Petrone 2010). The catchments in the Petrone (2010) study received 693 mm and Dallas, Texas received 1101 mm precipitation during their respective sampling periods (Aitkenhead-Peterson and Steele 2016).

Studies have found that DON in water and wastewater impacts water treatments and potentially forms nitrogenized disinfection byproducts with higher carcinogenicity and toxicity than carbonated disinfection byproducts (Chang et al. 2013). It also provokes membrane fouling because it supports microbial survival and growth (Her et al. 2004). Research shows that DON fractions in TDN after tertiary treatment effluents can sometimes be the dominant part (54%) of TDN (Chen et al. 2011).

1.5.3 DON: TDN ratio

Few studies have evaluated the impact of urbanization on DON:TDN ratios but it is important for determining the extent of impairment of a surface water. Illustrating the amount of inorganic nitrogen exports as reported by a study conducted in northern US states, stream water DON:TDN ratios of 0.35, 0.27 and 0.55 were reported for urban, agricultural and forested watersheds, respectively (Pellerin et al. 2004). Low ratios tend to indicate urbanization as illustrated by both Pellerin et al. (2004) and a study in urban and rural watersheds in south central Texas comparing the impact of sewage effluent on

DON:TDN ratios. The study reported that surface waters receiving point source effluent had ratios ranging from 0.13±0.10 to 0.24±0.23 and surface waters that were not receiving point source effluent had ratios of 0.57±0.21 to 0.74±0.14 (Aitkenhead-Peterson et al. 2009). Aitkenhead-Peterson and Steele (2016) also reported DON:TDN ratios ranging from 0.03 to 0.31 for urbanized watersheds in the upper Trinity River, Texas, USA.

1.6 Phosphorus

1.6.1 Phosphorus in surface waters

Phosphorus enrichment in surface waters can initiate undesirable changes in ecosystem structure and function. The enrichment of phosphorus leads to events such as increased plant growth, algal blooms, oxygen depletion, and the death of certain fish species, invertebrates and other aquatic animals (Bennett et al. 1999). The enrichment of phosphorus creates eutrophic surface waters that lead to the degradation of their ecological, economic and aesthetic value by restricting use for fisheries, drinking water, industry and recreation (Bennett et al. 1999). Eutrophication is the "*process by which water bodies are made more eutrophic through an increase in their nutrient supply*" (Smith et al. 1999). Phosphorus is the leading factor in eutrophication and has encouraged efforts to control phosphorus inputs (Bennett et al. 1999).

Higher total phosphorus and dissolved phosphorus concentrations are generally found in aquatic ecosystems of urbanized areas as a result of increased particle associated phosphorus from construction sites, un-sewered developments, runoff from lawn fertilizers and pet wastes (Smart et al. 1985;Carpenter et al. 1998;Sharpley 2006). Some studies link high fertilizer use to high phosphorus concentrations in urban streams; however, other studies found no evidence of this (Paul and Meyer 2001;Lewis et al. 2007). Estimates of phosphorus inputs from fertilizer use by urban lawns was found to be between 37,000 and 128,000 kg P year^{-1} to Lake Mendota in Wisconsin which is located in a watershed area of 686 km^2 that is currently being changed from agricultural land to urban land (Bennett et al. 1999). Legacy phosphorus in addition to the contemporary phosphorus use by homeowners may lead to many years of recovery to the lake.

Research has shown that even though runoff volumes from urban residential lawns are relatively low, runoff from these sites contribute 50-80% of the total annual loading of phosphorus in runoff (Bennett et al. 1999;Waschbusch 1999). When total and dissolved phosphorus concentrations from high maintenance and low maintenance lawns are compared to other residential sources, such as driveways and roofs, lawn runoff concentrations were 2-18 times larger (Bennett et al. 1999).

A study in Missouri Ozark Plateau Province examined the relationship between urban land practices, surface water chemistry and algal chlorophyll concentrations in streams (Smart et al. 1985). In general, concentrations of total phosphorus were highest in urban streams when compared to forest streams and pasture streams, and total phosphorus was strongly correlated with chlorophyll values (Smart et al. 1985). Chlorophyll is a green pigment present in all green plants which is responsible for the absorption of light to provide energy for photosynthesis and can be considered a measure of the buildup of organic matter in cyanobacteria, phytoplankton or algae in aquatic ecosystems (Schindler 1977;Zhang et al. 2009). The buildup of organic matter contributes to eutrophication through its death and decay when sediment microorganisms use the substrate and deplete the dissolved oxygen concentrations in the water column; thus controlling eutrophication requires reduction in phosphorus inputs.

1.6.2 Phosphorus transport

Phosphorus is typically tightly adsorped to soil minerals specifically iron and aluminum hydroxides and oxyhydroxides in soil such as allophones or imogolites (Lilienfein et al. 2004). If the soil is eroded and sediment is transported off site to surface waters, detachment of phosphorus from sediment in aquatic environments, particularly those with low dissolved oxygen, can impair water quality. McDowell and Sharpley (2003) analyzed the loss of phosphorus in sediment from soils that received P as manure and fertilizer and reported a decrease of loss of particulate P (PP) and total P (TP) in soil treated with manure (9.9 mg PP, 1.5 mg TP) when compared with an untreated soil (13.3 mg PP, 18.1 mg TP) due to the increased aggregation of the added carbon in manure. A major concern of sediment transport of phosphorus is in the form of organophosphates (commonly used in insecticides and herbicides) because of their aquatic toxicity (Bondarenko and Gan 2004). The sorption of organophosphates in urban creek sediments from southern California was studied and illustrated that the different desorption rates of organophosphates in stream sediments were highly dependent on redox conditions (Bondarenko and Gan 2004).

1.7 Carbon

Few studies have examined dissolved organic carbon (DOC) in urban ecosystems (Aitkenhead-Peterson et al. 2009;Petrone 2010;Aitkenhead-Peterson 2016). DOC is a significant part of the carbon cycle and its concentrations have been increasing significantly by about 10% in northern hemisphere surface waters (Evans et al. 2005). Its increased concentration has been attributed mainly to recovery from the acid rain era (i.e. increase in soil pH) and climate change (Willey et al. 2000). As soil pH increases so does the solubility of DOC, specifically humic fractions. The importance of DOC exports in urban ecosystems is that it quantifies the loss of terrestrial organic carbon and thus sequestered C (Aitkenhead-Peterson et al. 2009). In areas where urban land use is 6-100%, research showed annual mean concentrations of DOC to be 20.4 mg L^{-1} to 52.5 mg L^{-1} with relatively higher concentrations in watersheds with a WWTP in central Texas (Aitkenhead-Peterson et al. 2009). When residential lawns are first seeded or sod is established, the use of biosolid compost amendments to soil low in organic matter is often considered to supply the necessary nutrients for plant growth (Linde and Hepner 2005). Research has shown that the application of biosolid compost can increase DOC concentrations in soil solution and can potentially increase DOC concentration and exports in runoff to urban aquatic ecosystems (Wright 2005).

In urban and other land use soils, DOC is either mineralized by microbes through respiration or retained in the soil by adsorption to soil minerals, with only a small portion released to runoff to aquatic ecosystems (Volk et al. 1997;Marschner and Kalbitz 2003;Aitkenhead-Peterson and Cioce 2013;Cioce and Aitkenhead-Peterson 2015). DOC is a substrate for aquatic and terrestrial heterotrophs (Cioce 2012). Losses of terrestrial DOC to surface water has been implicated in the formation of trihalomethane when surface water is used as a drinking water source (Worrall et al. 1997), in the recovery and regrowth of *E. coli* in aquatic ecosystems (McCrary et al. 2013), in transport of metals by affecting metal solubility and mobility, and in trasnport of novel carbon compounds found in pesticides and herbicides (Worrall et al. 1997).

1.8 Cations

Ion concentrations in surface and ground waters are generally the result of bedrock weathering and depending on the geology may be quite high particularly during surface water baseflow when streamflow is groundwater fed. Impervious surfaces in highly urbanized watersheds can limit the interactions between water and bedrock due to lack of infiltration of water to the water table, which in turn limits the interactions between water and deeper minerals (Connor et al. 2014). Urban infrastructure such as concrete increases the availability of ions in runoff because of mineral leaching from the concrete (Rose 2007). A study reported a 3-4 fold increase in calcium, magnesium, and sodium in water samples derived from an urbanized watershed relative to rural watersheds along the Chattahoochee River which drains rural and urban landscapes in Georgia, Alabama, and Florida (Rose 2007;Connor et al. 2014). The Anacostia River, a major urban watershed in Washington, D.C., had greater concentrations of sodium, magnesium, calcium, and potassium which were not reflective of the geology and exemplified characteristics of “urban stream syndrome,” in which the urban landscape is concomitantly linked to the geochemistry of the river system (Connor et al. 2014).

The sampling of runoff is often used to examine the effects of land use and land management on water quality. Urbanization typically increases runoff to streams because of the high proportion of impervious surfaces, introduced sediment, and mobilized chemical species. Studies have examined the relationship between major inorganic ion concentrations and land use, in which population density has the greatest influence in ion chemistry (Bhatt and McDowell 2007;Lewis et al. 2007;Bahar and Yamamuro 2008). A study in Japan, examined the major ion chemistry of river water, where urbanization and construction was still in progress, and reported a positive correlation with urban development and Ca^{2+} (8.8 mg L^{-1}), and low-rise residential areas with Ca^{2+} and Mg^{2+} (9.6 and 6.6 mg L^{-1}) (Bahar and Yamamuro 2008). Cations tended to have higher concentrations during baseflow in a rapidly expanding urban area in central Texas (Harclerode et al. 2013). Here Ca^{2+} concentrations ranged from 9.4-20.4 mg L^{-1} during baseflow and from 11.0-15.6 mg L^{-1} during stormflow (Harclerode et al. 2013). Unlike the Bahar and Yamamuro (2008) study, there were no positive and significant correlations with stream cations and percent urbanization of the watersheds except for Na^{+} (Harclerode et al. 2013). Another study in South Carolina reported higher concentrations for Na^{+}, K^{+}, Ca^{2+}, and Mg^{2+} in urban streams that decreased downstream of the urban center (Lewis et al. 2007).

High ion concentrations in irrigation water used in urban areas may have harmful effects on soil hydraulic properties (Smith et al. 2015). Research concluded that of the four common cations in soils, Na^+ had the greatest effect on soil hydraulic properties followed by K^+, Mg^{2+}, and Ca^{2+} (Smith et al. 2015). Strong and significant relationships between aquatic or soil DOC and DON concentrations and sodium have been reported locally in central Texas as well as internationally in Australia (Skene and Oades 1995;Holgate et al. 2011;Steele and Aitkenhead-Peterson 2012;Aitkenhead-Peterson and Cioce 2013;Tavakkoli et al. 2015). The release of DOC and DON has been linked to irrigation water high in sodium concentrations shown by research from vegetation and soil at the laboratory, microcosm and small plot scales (Holgate et al. 2011;Pannkuk et al. 2011;Mavi et al. 2012;Steele and Aitkenhead-Peterson 2012;Aitkenhead-Peterson and Cioce 2013). High sodium has also been linked to greater DOC release from soil adsorption sites and concomitant reactive soil C pools (Aitkenhead-Peterson and Cioce 2013). Reduction in microbial mineralization of DOC, particularly in urban highly managed turfgrass and soils has also been caused by irrigation with sodic water (Cioce and Aitkenhead-Peterson 2015). This may be due to the increased solubility of DOC with increasing pH as addition of sodium within irrigation water will eventually create sodic soil conditions with high pH soils (> 8.5).

1.9 Wetting agents

Research on wetting agents began in the mid-1950's after the introduction of the first commercially available wetting agent, which due to their cost, was principally used in golf courses to improve soil conditions and increase water infiltration (Rice and Horgan 2011). In 2004, a survey was conducted of more than 600 superintendents of golf courses and found that 87% used wetting agents as part of their regular maintenance to relieve localized dry spots, managing water, improving drainage, and improve pesticide movement into the soil (Karnok et al. 2004). Wetting agents have also been used in agricultural soils and sandy soils in Australia where research has shown positive impacts and increased yields in potatoes by up to 20% and improved tuber quality (Mitra et al. 2006;Hallett 2007).

In many countries soils exhibit soil water repellency or hydrophobicity in which the primary effect is the reduction of water infiltration, but it can also affect water movement within the soil (Wallis and Horne 1992;Hallett 2007). A hydrophobic soil will express pooling on the surface where water will not infiltrate the soil and can be caused by the presence of hydrophobic organic materials produced by plant root exudates, certain fungal species, surface waxes from leaves, and decomposing soil organic matter that coats the soil particles (Wallis and Horne 1992;Hallett 2007). This can have negative effects on water uptake by plants, resulting in poorer yield and water infiltration, thus increasing water runoff (Wallis and Horne 1992;Hallett 2007;Shearman 2008). Research also shows that hydrophobicity may enhance preferential flow, increasing chemical leaching to groundwater (Täumer et al. 2006).

Wetting agents, also known as nonionic surfactants, are used as a novel approach to water conservation because they provide the most immediate solution to combating soil water repellency when compared to other physical, chemical and biological approaches, particularly on large commercial areas (Dekker et al. 2005;Hallett 2007;Cisar 2012). Wetting agents typically posses a water soluble hydrophillic group attached to a long, oil soluble lipophillic hydrocarbon chain (Fig. 1.1) and cause physical changes at the surface of liquids (Karnok et al. 2004). At the molecular scale, the polar portion of the wetting agent will bond to the water while the nonpolar portion will bond to the nonpolar organic coating, thus allowing the water to wet the soil particle (Fig. 1.2-1.3) (Karnok et al. 2004). These products are also able to disrupt the cohesive forces of water molecules responsible for expressing surface tension, thus decrease the surface tension of the liquid and therefore increase infiltration rate and allow for better penetration of water into a hydrophobic soil (Schiavon et al. 2014b). Because wetting agents are typically nonionic they do not ionize in aqueous or water solution (Karnok et al. 2004) and do not react with other ions, therefore do not form insoluble salts with calcium, magnesium or ferric ions. They also have relatively low toxicity to plants (Karnok et al. 2004).

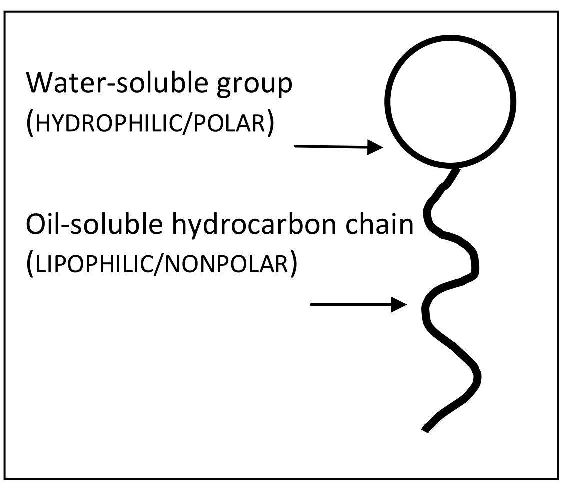


Fig. 1.1. A typical wetting agent molecule (Modified from Karnok et al. 2004)

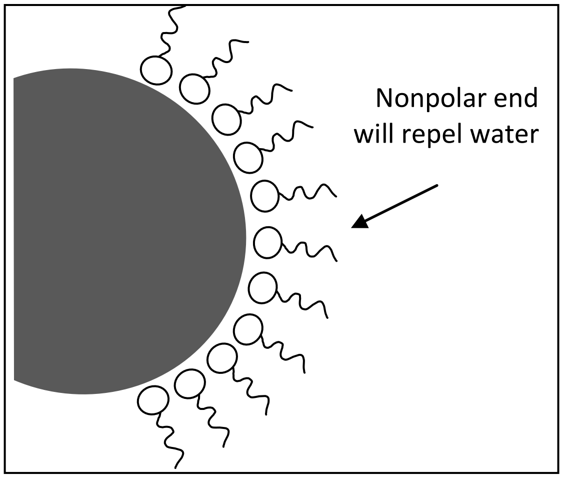


Fig. 1.2. Diagram of a sand particle with a water repellent organic coating (Modified from Karnok et al. 2004)

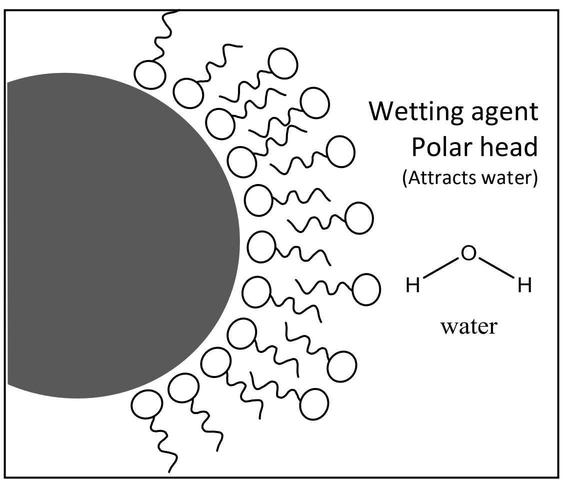


Fig. 1.3. Diagram of a sand particle with a water repellent organic coating after treatment with wetting agent (Modified from Karnok et al. 2004).

Little information is published concerning the effectiveness of these wetting agents in the reduction of runoff but previous research on wetting agents or surfactants, have shown increased infiltration into soils and runoff reduced significantly in the early 1960's (Morgan et al. 1966). However, a study in the Netherlands on the water repellent sands of a sloped fairway lower runoff and increased soil moisture after the application of soil surfactant was observed (Oostindie et al. 2005). Mitra et al. (2006) reported an infiltration rate 1.4 times higher in a treated loamy sand with established hybrid bermudagrass turf maintained under fairway management conditions than that of an untreated loamy sand, and an increased time to runoff from 20 minutes to more than 40 minutes. There was also a reduction in total runoff by 30% on a loamy sand soil with 8% slope compared to an untreated loamy sand soil with 8% slope with an established hybrid bermudagrass turf maintained under golf course fairway management conditions (Mitra et al. 2006). A non-ionic surfactant composed of 89.5% alkylphenol ethoxylate, sodium salts of soya fatty acids, isopropyl alcohol and 10.5% unknown constituents applied to a potato hill increased inorganic nitrogen retention and reduced inorganic nitrogen leaching (Arriaga et al. 2009). It also resulted in greater amounts of nitrogen taken up by the plants (Arriaga et al. 2009). Since these products have been effective in commercial and agricultural studies, there is interest in expanding their use to home lawns. If indeed these products are effective in increasing water infiltration into the soil, improving distribution and availability of water in soils affected by soil water repellency (SWR), they should also reduce the amount of runoff as well as the total amount of nutrients lost via runoff (Park et al. 2005;Mitra et al. 2006).

The aims of this study were to a) quantify the exports of DOC, DON, PO_4-P, and cations from fertilized and unfertilized St. Augustine grass under different treatments of deficit irrigation and fertilization and b) to quantify the effectiveness of the regular applications of wetting agent to reduce exports of N, P, and water from St. Augustine grass lawns. Further, the aim was to determine if exports of DOC and DON were related to cation losses based on the theory of maintenance of electroneutrality in runoff water.

CHAPTER II

LOSSES OF DISSOLVED ORGANIC CARBON, DISSOLVED ORGANIC NITROGEN, AND CATIONS IN SURFACE RUNOFF FROM ST. AUGUSTINE GRASS LAWNS

2.1 Introduction

The growing population in the United States has led to the growth of urban and suburban areas and the concomitant installation of green space as well as grey space which dominates the landscape (Colby and Ortman 2015). Turfgrass is commonly used for lawns, recreational areas and aesthetic purposes and is the major form of green space (Milesi et al. 2005). To illustrate, turfgrass covers an estimated 16 million hectares in the United States of which 1.9% is represented by urban residential, commercial, and institutional lawns, parks, golf courses, and athletic fields (Milesi et al. 2005). Residential lawns can demand high input management systems such as the use of fertilizers, pesticides, herbicides, and often the installation of an in-ground irrigation system in order to maintain the aesthetic and functionality of a lawn. The mismanagement of these turfgrass systems can lead to unfavorable situations in aquatic ecosystems. For example, the misuse use of fertilizer is purported to lead to excess inorganic N and P lost to runoff (Carpenter et al. 1998). Inorganic N and P in surface waters cause detrimental harm to the aquatic ecosystem, such as increased algal blooms and eutrophication (Howarth et al. 1996). While inorganic forms of N and P in urban ecosystems are highly researched, the losses of DON, DOC, and major cations from urban landscapes to urban streams have received less attention (Aitkenhead-Peterson et al. 2009;Petrone 2010;Kaushal et al. 2014;Smith and Kaushal 2016). Losses of DON and DOC are also a concern because they are a significant component of nutrient export (Seitzinger et al. 2005a).

2.1.1 DOC and DON

DOC and DON are the major fractions of dissolved organic matter (DOM) and therefore are found in every undisturbed and minimally disturbed terrestrial and aquatic ecosystem (Aitkenhead-Peterson et al. 2003;Aitkenhead-Peterson et al. 2009). DON and DOC compose the majority of the total C and N load and their exports reflect the loss of terrestrial N and C to surface waters from rapidly expanding urban ecosystems (Aitkenhead-Peterson et al. 2009;Petrone 2010). The delivery of DON and DOC to urban aquatic ecosystems illustrates the importance of the source and bioavailability of DOM and the effectiveness of urban water retention management practices.

While few studies have examined DOC in urban ecosystems, it is significant to the carbon cycle and important to a wide variety of chemical, physical, and biological processes in surface waters. DOC concentrations have been significantly increasing by about 10% in northern hemisphere surface waters postulated to be due to recovery from acid rain and climate change (Willey et al. 2000;Evans et al. 2005). In aquatic ecosystems (Wiegner and Seitzinger 2004;Seitzinger et al. 2005b;Cioce 2012) it functions as a substrate source for aquatic heterotrophs in a similar manner to terrestrial heterotrophs (Cioce and Aitkenhead-Peterson 2015).

In urban and other land use soils, DOC is either mineralized by microbes through respiration or retained in the soil by adsorption to minerals, with only a small portion released to runoff to aquatic ecosystems (Volk et al. 1997;Marschner and Kalbitz 2003;Aitkenhead-Peterson and Cioce 2013;Cioce and Aitkenhead-Peterson 2015). When compared to residential lawns and remnant native soils, release of DOC and its reactive C pool in soils under parks is much higher (Aitkenhead-Peterson and Cioce 2013). For example, golf courses, sports fields and neighborhood parks with turfgrass contribute to 68% of the variability in mean annual DOC concentrations in watersheds in Central Texas (Aitkenhead-Peterson et al. 2009).

Fewer studies have examined DON concentrations and exports from urban ecosystems (Aitkenhead-Peterson et al. 2009;Petrone 2010;Steele and Aitkenhead-Peterson 2012;Wherley 2015). DON is that subset of the DOM pool that contains mobile organic forms of nitrogen that are bioavailable to microorganisms in most aquatic systems (Bronk 1997). Compounds including urea, dissolved combined amino acids, dissolved free amino acids, humic and fulvic substances, and nucleic acids have been identified within the DON pool (Bronk 1997). Evidence suggest that DON provides the nitrogen nutrition for survival and growth (Her et al. 2004) to phytoplankton including a number of harmful aquatic species (Bronk et al. 2007). Studies have also found that DON in water and wastewater is a precursor to the formation of nitrogenized disinfection byproducts which have higher carcinogenicity and toxicity than carbonated disinfection byproducts towards humans (Chang et al. 2013).

Contrary to biogeochemical theory, DON is dominant in urban catchments and may constitute a significant component of total dissolved nitrogen (TDN) typically representing 40-50% of the total N in streams and lakes but may also represent greater than 85% of the TDN in undisturbed watersheds (Willett et al. 2004;Petrone 2010). DON can act as an indicator of mechanisms within the soil such as nitrogen limitation or saturation (Perakis and Hedin 2002). Research shows that DON fractions in TDN after tertiary treatment effluents can sometimes be the dominant part (54%) of TDN (Chen et al. 2011). A recently reported source of DON to urban ecosystems is through precipitation and throughfall (de Souza et al. 2015). In a study in Brazil, DON accounted for 32-56% and 26-32% at urban and forest sites, respectively of total dissolved N in precipitation, with urea comprising up to 100% of the DON (de Souza et al. 2015).

2.1.2 Orthophosphate

Phosphate bound or tied up in plant tissue, waste solids, or organic material can be converted to orthophosphates, which can provide a good estimation of the amount of phosphorus in surface water (Oram 2006). Orthophosphate in urban environments results from mineral deposits and bedrock but anthropogenic activities also contribute through partially treated and untreated sewage effluent, industrial effluents, cleaning supplies, animal waste, and the application of lawn fertilizers (Oram 2006). Measuring and regulating nonpoint source inputs of phosphorus are challenging because they derive from activities dispersed over wide areas of land and are variable in time due to effects of weather (Carpenter et al. 1998). Orthophosphates applied to residential lands as fertilizers can be carried into the surface waters during storm events or snow melts (Oram 2006). Research has shown that even though runoff volumes from urban residential lawns are relatively low, runoff from these sites can contribute 50-80% of the total annual loading of phosphorus in runoff (Bennett et al. 1999;Waschbusch 1999).

Legacy phosphorus is defined as the phosphorus within a watershed that has accumulated as a result of previous land and nutrient management (Sharpley et al. 2013). The accumulation of P in soils arises when P addition exceeds the requirement for crop uptake. In agricultural soils, accumulation of P represents the most pervasive legacy source of P to the environment and can take decades for excess P to decline, depending on how much P has accumulated in the soil (Sharpley et al. 2013). Phosphorus accumulation across watersheds is the result of not only anthropogenic activities but of complex interactions of soil hydraulic, hydrology, and geomorphology (Sharpley et al. 2013). Legacy phosphorus in addition to the contemporary phosphorus use by homeowners may lead to many years of recovery to surface waters.

Phosphorus enrichment in surface waters can initiate and speed the natural aging process of lakes and lead to eutrophication in lakes across the United States, causing degradation of the ecological, economic, and aesthetic values of surface waters by restricting their use for fisheries, drinking water, industry, and recreation (Bennett et al. 1999;Oram 2006). Phosphorus is the leading factor in eutrophication and has encouraged efforts to control phosphorus inputs (Bennett et al. 1999). If current anthropogenic practices continue, nonpoint source inputs of phosphorus to surface waters is likely to increase.

2.1.3 Major cations

Rock weathering and geology contribute significant portion of the ions found in surface and ground water which cause most of the hardness in water, greatly affecting the value of water for public and industrial uses. Generally major cations in surface waters are derived from groundwater as a function of weathering of the parent material and the residence time of the groundwater. A study by Aitkenhead-Peterson et al. (2011) examined cations at baseflow and high flow from 13 urban and rural streams and included the expected chemical makeup of baseflow derived from local geology compared to that of the geology of the aquifer from where the municipal tap water was sourced. With the exception of watersheds receiving sewage effluent, most of the urban streams had the same anion and cation signature as municipal tap water rather than the signature of their underlying geology suggesting that irrigation water chemistry may drive stream chemistry profiles in urban watersheds in southern US states where landscape irrigation is prolific. The interaction between infiltrated soil water and bedrock rock may also be altered by urbanization as a result of leaching from the high portion of impervious surfaces and concrete (Rose 2007;Connor et al. 2014). Urbanization typically increases runoff to streams because of the high proportion of impervious surfaces which can include compacted soils of green space as well as the traditional grey space. The leaching of alkali from concrete/cement and other urban infrastructures were linked to the geochemistry of the Anacostia River system (Connor et al. 2014). Studies have examined the relationship between major inorganic cation concentrations and land use, in which population density has had the greatest influence in cation chemistry (Bhatt and McDowell 2007;Lewis et al. 2007;Bahar and Yamamuro 2008).

High cation concentrations of sodium and potassium in irrigation water impact soil structural stability, swelling, and dispersion of clay which adversely affects plant growth (Arienzo et al. 2012;Smith et al. 2015). In a study examining municipal tap water and water extractable soil DOC, DON, and PO_4-P, in 26 cities across the state of Texas, Steele and Aitkenhead-Peterson (2012) found that the sodium adsorption ratio (SAR), (a measure of Na^+ compared to Ca^{2+} and Mg^{2+}), when greater than 5 in irrigation water was significantly correlated with DOC losses (R^2 = 0.62) and explained 72% of the variability in DON release from soil. The best predictor of PO_4-P loss was the percent of Na^+ in irrigation water (R^2 = 0.56) (Steele and Aitkenhead-Peterson 2012). Irrigation with sodic water reduces microbial mineralization of DOC, particularly in urban highly managed turfgrass (Cioce and Aitkenhead-Peterson 2015). High sodium has also been linked to greater DOC release from soil adsorption sites and concomitant reactive soil pools (Aitkenhead-Peterson and Cioce 2013). The release of DOC and DON has been linked to high sodium concentrations in irrigation water (Aitkenhead-Peterson and Cioce 2013).

2.1.4 Objectives and hypothesis

The objectives of this study were:

To quantify the exports of dissolved organic carbon, dissolved organic nitrogen, sodium, potassium, magnesium, and calcium from fertilized and unfertilized St. Augustine grass under three different treatments of deficit irrigation and two nitrogen fertilization treatments

To determine if the exports of dissolved organic carbon and dissolved organic nitrogen are related to cation losses based on the theory of maintenance of electroneutrality of water.

My hypotheses were:

H_0: There will be no significant difference among the exports of DOC and DON when comparing deficit irrigation and fertilization treatments

$H_{1:}$ Exports of DOC and DON will be significantly higher in treatments receiving 60% ET_o irrigation and high fertilization compared to treatments receiving 30% ET_o irrigation and low fertilization because optimal conditions will result in enhanced turfgrass growth and vegetation leaching

H_2: Exports of DOC and DON will be significantly higher in treatments receiving 30% ET_o irrigation and low fertilization compared to treatments receiving 60% ET_o irrigation and high fertilization because poor conditions will result in death and decay of turfgrass and leaching of DOC and DON

H_0: There will be no significant relationship between exports of DOC and DON and cation exports

H_1: There will be a significant relationship between exports of DOC and DON and cations, specifically Ca^{2+} losses because enhanced Na^+ in irrigation water will displace Ca^{2+} from soil exchange sites and DOC and DON will be released to maintain electroneutrality

2.2 Materials and methods

2.2.1 Study site

Research was conducted at the Texas A&M University/Scotts Miracle Gro Runoff Research Facility at the Texas A&M Urban Ecology Field Laboratory, in College Station, TX (N 30.618178, W -96.366250). The 1,000 m^2 facility contained 24 individual 33.6 m^2 field plots with an average slope of 0.037 m m^{-1} were used to measure total runoff volumes at a 2 minute temporal resolution and simultaneously collect runoff water on a native undisturbed soil with natural variability and microclimate effects (Wherley et al. 2014). The plots had individual plot irrigation, and plastic barriers installed to a depth 0.5 m between plots to prevent lateral movement of subsurface water between plots, small above ground berms to prevent lateral movement of surface water between plots, and a tile drain above the plots to prevent upslope water from getting onto the experimental runoff plots (Fig. 2.1).

Fig. 2.1. Plastic inserts to avoid lateral flow on the plots. Installation of drain to prevent run-on and an H flume used to measure runoff volume. Source: Turf Team, Texas A&M University.

The plots had a retaining wall at the bottom which included Zurn drains as runoff collection troughs which allowed the collection of all runoff from each plot and delivery of it to flumes for measurement and sampling. A 1.27 cm slope to the drain allowed unimpeded water flow from the soil to the drain which connected to a 1.2 m long H flume, below the drain outflow, installed with a flow meter and portable sampler. Reinforced steel concrete pads, 1.2 m wide, 1.8 m long and 15 cm thick below each drain outflow had a 0.5% slope away from the wall. Stainless steel covers between the wall and the flumes prevented precipitation from entering the Zurn drains and flumes. More detailed description of the design and construction of the urban runoff research facility is available in, Wherley et al. (2014).

There are two soil series at the study site (Fig. 2.2). The Boonville (BoB series is a fine, smectitic, thermic Chromic Vertic Albaqualf generally occurring on 0-3% slopes and is present on Blocks 1 and 2 (Table 2.1). The Zack (ZaD) series is a fine, smectitic, thermic Udertic Paleustalfs generally occurring on a 1-5% slopes and is present on Blocks 2 and 3 (Fig. 2.2). The depth of the topsoil to the clay at the runoff plots ranged from 0.305 to 0.405 m in Block 1, from 0.26 to 0.515 m in Block 2, and from 0.25 to 0.40 m in Block 3 (Wherley et al. 2014). There was no significant difference in topsoil depth when comparing blocks (2-sample 2-tail test).

Fig. 2.2. Soil series at the study site. BoB – Boonville Series and ZaD – Zack Series. Source: Modified from SoilWeb, http://casoilresource.lawr.ucdavis.edu/soil_web/.

Table 2.1. Characteristics of the two soil series at the study site. Source: SoilWeb, http://casoilresource.lawr.ucdavis.edu/soil_web/.

Depth Range (cm)	Clay (%)	Sand (%)	Organic Matter (%)	pH by water Extraction	Sat. Hydraulic Conductivity (mm/hr)	CEC at pH 7 (cmol charge/ kg soil)
Boonville Series						
0 – 43	10.0	68.5	0.75	6.2	32.40	6.0
43 – 91	45.0	26.1	0.75	6.8	0.76	27.5
91 - 185	32.5	34.7	0.75	7.9	3.60	22.5
185 - 224	40.0	29.6	0.75	7.0	3.60	32.5
Zack Series						
0 – 8	11.0	67.7	0.65	5.8	32.40	7.5
8 – 38	50.0	22.1	0.60	6.5	0.76	37.5
38 - 76	45.0	26.1	0.40	7.0	0.76	37.5
76 - 152	25.0	38.5	0.30	7.9	3.60	22.5

The previous land use at this site was cattle grazing for a dairy farm and so the probability for soils saturated with legacy phosphorus is high.

St. Augustine (*Senotaphrum secundatum* (Walt.) Kuntze) turfgrass was installed as a sod in August and September 2012 (Wherley et al. 2014). St. Augustine grass is a fast growing, stoloniferous perennial grass adapted to warm, coastal regions of the United States and often the most common choice for residential urban and suburban lawns in southern United States and predominant in Texas (CA, NM, TX, OK, LA, MO, MS, TN, VA, NC, SC, AL, GA, FL; Fig. 2.3).

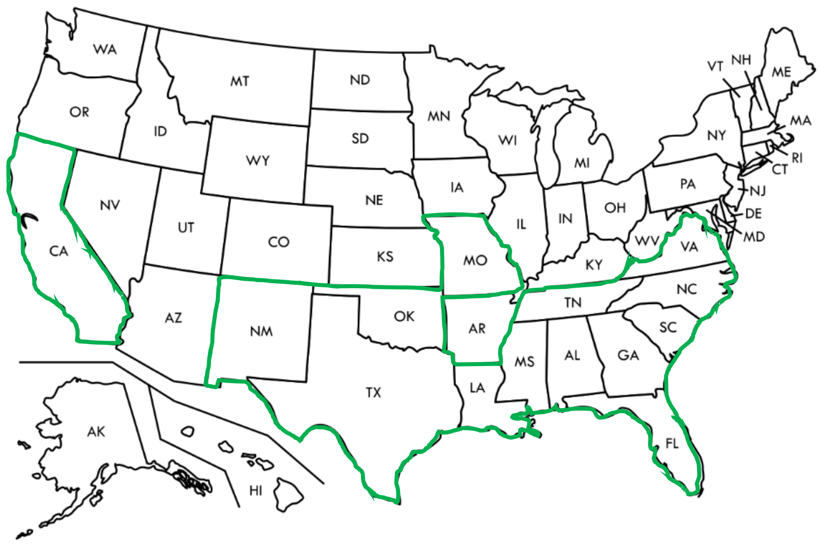


Fig. 2.3. Native map of St. Augsutine grass in the United States. "Stenotaphrum secundatum (Walter) Kuntze". (Modified from USDA PLANTS).

The climate in this region is humid subtropical with a mean annual temperature of 20° C and an annual average precipitation of 1,000 mm (Aitkenhead-Peterson et al. 2009).

2.2.2 Experimental design

Turfgrass plots were maintained to accommodate commonly imposed Texas homeowner irrigation regulations, which allow for two irrigation days per week. The turfgrass was mowed weekly using a standard push rotary mower with mulching blades set to a 6.3 cm height of cut with the clippings were returned. Periodic disease and weed management were performed across all plots based on historical knowledge of the area. Municipal irrigation water at the site had a sodium adsorption ratio of 32 ± 5 mg L^{-1}, so to reduce the impact of sodic irrigation, gypsum was applied at a rate of 2.24 mg ha^{-1} on 6th January 2013 and 26th March 2014. Between the addition of gypsum and the start of treatments runoff collection in Year 1 (2013), 225 mm rain fell and 33 mm rain fell between the addition of gypsum and start of treatments and runoff collection in Year 2 (2014).

Fertilizer treatments of two or four applications were also imposed. Nitrogen fertilizer is frequently applied in the form or urea in combination with some form of slow release materials, rather than in immediately available forms. Fertilizer applied was a Southern Turf Builder (32-0-10, N-P_2O_5-K_2O; Scotts Miracle-Gro, Marysville, OH) at a single rate of 44 kg N ha^{-1} per application but varied in number of applications per year (0x, 2x, 4x) (Table 2.2.). The first application was made in May of 2013 and subsequent applications were made every 6 or 12 weeks after following the assigned treatment (Table 2.3). Fertilizer was lightly watered into plots immediately after application with 2.5 mm of irrigation water and the day before an irrigation event. Temperature data (average ºC) were obtained from Weather Underground archives for station KCLL. Rainfall volumes (mm) on site were measured using a tipping rain gauge (Isco 647, Teledyne Isco, Lincoln, NE) at a two minute temporal resolution. Each plot was equipped with a 1.2 m H flume, an Isco model 4230 Bubbler Flow Meter, and an Isco model 6712 Portable Sampler that collected the rain or irrigation induced runoff (Teledyne Isco, Lincoln, NE 68504). For year 2013, 6 rain runoff events and one irrigation-induced runoff event were captured. Forced runoff was initiated by irrigating at an average precipitation rate of 37.6 mm hr^{-1} for a 30 min period delivering an average of 18.8 mm. Each plot had its own totalizing water meter to record the volume of irrigation water applied. Water volumes added to each plot were recorded and used in analysis. For year 2014, 9 runoff events were captured.

Based on typical residential management use, eight treatments were established (Table 2.4), having three replicates arranged randomly within three blocks (Table 2.2). Irrigation was applied on Tuesdays and Fridays to accommodate the two day per week irrigation schedule allowed in many Texas cities. Chemistry of the irrigation tap water is shown in Table 2.5. The irrigation run time was adjusted to apply amounts equal to the cumulative evapotranspiration deficit which was calculated as:

$$\mathrm{ET_{Def}} = \sum \llbracket \mathrm{K_s} * \left[0.6 * \mathrm{ET_o} - R_{eff}\right]\rrbracket$$

Where K_s is a stress coefficient, 0.6 is the warm-season turfgrass crop coefficient, ET_o is the daily reference ET calculated using the FAO-56 Penman Monteith method and R_{eff} is the daily effective rainfall (Allen et al. 1998). Treatments were defined as 60 ET_o, 45 ET_o, and 30 ET_o to create well-watered, stressed and severely stressed conditions for the turfgrass, respectively.

Table 2.2. Plot plan with treatments

	BLOCK 1							
Plot	1	2	3	4	5	6	7	8
ETo	30%	60%	45%	45%	60%	60%	30%	45%
Irrigation (mm week)	12.7	25.4	19.03	19.03	25.4	25.4	12.7	19.03
Irrigation (d w^{-1})	2	2	2	2	2	2	2	2
Runoff	Rain	Rain	Rain	Rain	Rain	Rain	Rain	Rain
Fertilizer	STB	STB	STB	STB	None	STB	STB	None
Fertilizer Application	4	2	4	2	0	4	2	0

	BLOCK 2							
Plot	9	10	11	12	13	14	15	16
ETo	60%	45%	30%	30%	45%	60%	60%	45%
Irrigation (mm week)	25.4	19.03	12.7	12.7	19.03	25.4	25.4	19.03
Irrigation (d w^{-1})	2	2	2	2	2	2	2	2
Runoff	Rain	Rain	Rain	Rain	Rain	Rain	Rain	Rain
Fertilizer	STB	STB	STB	STB	STB	None	STB	None
Fertilizer Application	2	4	4	2	2	0	4	0

	BLOCK 3							
Plot	17	18	19	20	21	22	23	24
ETo	30%	60%	45%	45%	60%	30%	45%	60%
Irrigation (mm week)	12.7	25.4	19.03	19.03	25.4	12.7	19.03	25.4
Irrigation (d w^{-1})	2	2	2	2	2	2	2	2
Runoff	Rain	Rain	Rain	Rain	Rain	Rain	Rain	Rain
Fertilizer	STB	STB	STB	STB	None	STB	None	STB
Fertilizer Application	2	2	2	4	0	4	0	4

Table 2.3. Fertilizer application dates

Year	Fertilizer application	
	$2x\ yr^{-1}$	$4\ x\ yr^{-1}$
2013	5/15/2013	5/15/2013
		6/26/2013
	8/7/2013	8/7/2013
		9/16/2013
2014	5/5/2014	5/5/2014
		6/16/2014
	7/28/2014	7/28/2014
		9/8/2014

Table 2.4. Plot treatments for fertilizer application

Treatment #	ET_o (%)	Yearly Irrigation ($cm\ yr^{-1}$)	2013 cumulative rainfall (mm)	2014 cumulative rainfall (mm)	Irrigation water each plot (L)	Fertilizer ($kg\ N\ ha^{-1}$)
1	60	26.59	520.1	662.9	89,342	0
2	45	19.93	520.1	662.9	66,964	0
3	60	26.59	520.1	662.9	89,342	44 (2*)
4	45	19.93	520.1	662.9	66,964	44 (2*)
5	30	13.30	520.1	662.9	44,688	44 (2*)
6	60	26.59	520.1	662.9	89,342	44 (4*)
7	45	19.93	520.1	662.9	66,964	44 (4*)
8	30	13.30	520.1	662.9	44,688	44 (4*)

*Number of applications

Table 2.5. Chemistry of tap water and rain water

	pH	EC	Na^+	K^+	Mg^{2+}	Ca^{2+}	SAR
		$\mu S\ cm^{-1}$	$mg\ L^{-1}$				
Municipal Water	8.4±0.1	648±35	206±25	3±3	0.4±0.1	3.0±0.1	32±5
Rain Water	6.7±0.3	37±29	6±5	1±1	0.2±0.2	0.8±0.6	1.5±0

2.2.3 Sample collection and processing

Six rain events were captured after treatments started in 2013 and one forced irrigation event was initiated (Fig. 2.4A). In 2014 nine rain events were captured after treatments started (Fig. 2.4B).

Five, evenly spread samples for each rain or forced irrigation event for each plot were collected for analysis. The pH (Excel XL20, Fisher Scientific, Pittsburgh, PA, USA) and electrical conductivity (Excel XL20, Fisher Scientific, Pittsburgh, PA, USA) were quantified on unfiltered samples. Samples were filtered through a 0.7 µm filter paper (Grade F, Lab Depot Inc., Dawsonville, GA, USA) prior to chemical analysis.

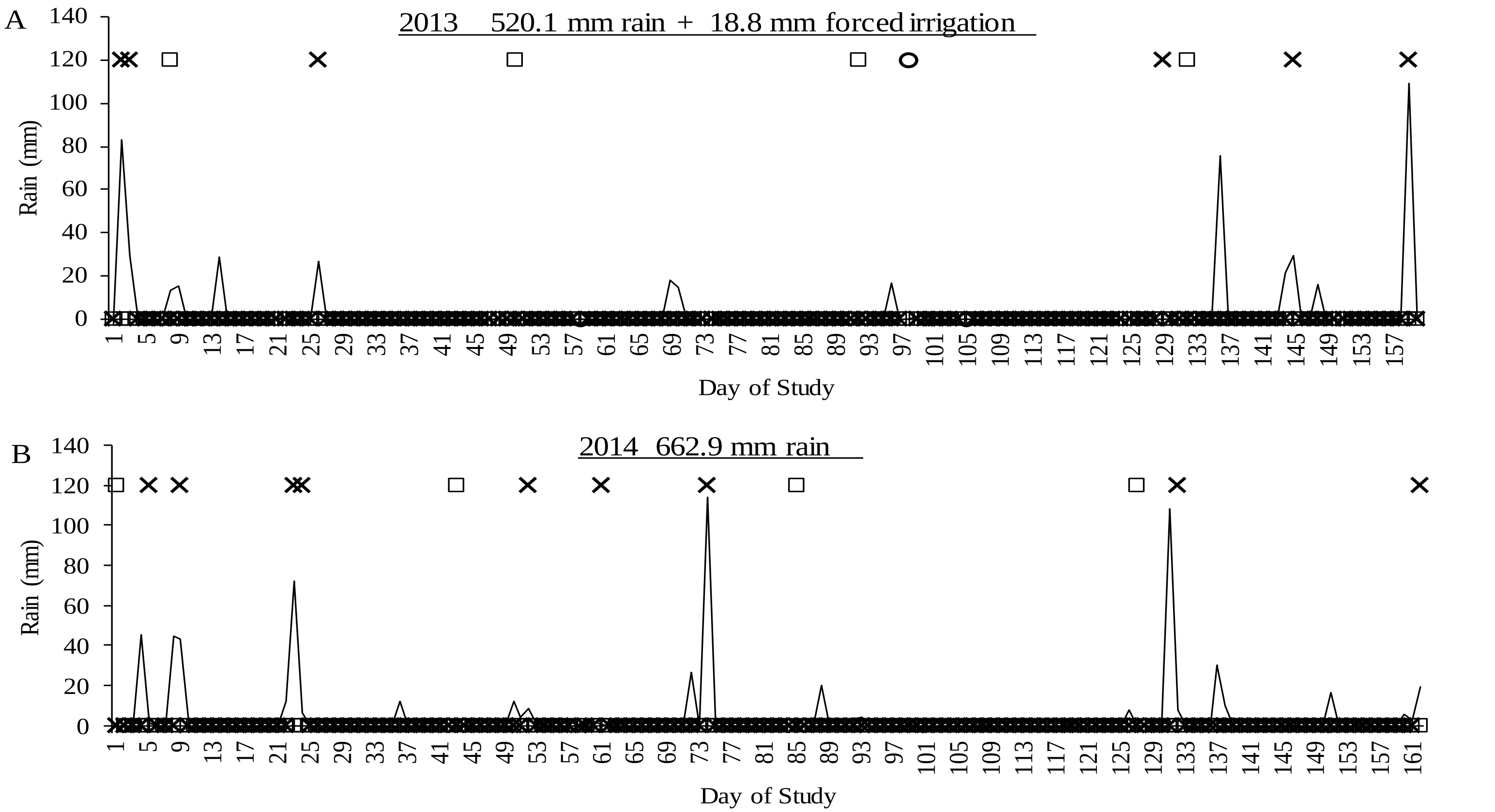


Fig. 2.4. Rain events for A) 2013 and B) 2014. Rain events that induced runoff for capture are denoted by X, forced irrigation denoted by O, and fertilizer application denoted by □.

2.2.4 Chemical analysis

All nitrate-N was analyzed within 18 hour of sample collection. All samples were analyzed for other parameters within 2-3 days of collection or frozen for future analysis. Samples for cation analysis were syringe filtered through PALL 0.2 µm cellulose filters. Determination of DOC followed the EPA method 415.3. DOC and TDN was measured using high temperature Pt-catalyzed combustion with a Shimadzu TOC-VCSH with N Detector. (Shimadzu Corp., Houston, TX, USA). DOC was measured as non-purgable carbon which entails acidifying the sample (250 mL 2M HCl) and sparging for 4 min with C-free air. Nitrate-N was analyzed using Cd-Cu reduction and N-(1-naphythyl)-ethylenediamene dihydrochloride to yield a colored azo dye that is colorimetrically detected at 550 nm, following the EPA method 353.2. NH_4-N was analyzed using phenate hypochlorite with a Na-nitroferricyandide (pH 12.8-13) to produce a blue-green color detected at 660 nm. Orthophosphate-P was analyzed using the ammonium molybdate EPA method 365.1. All colorimetric methods were performed with a Westco Scientific Smartchem Discrete Analyzer (Westco Scientific Instruments Inc., Brookfield, CT, USA). Calcium, magnesium, potassium and sodium were quantified by ion chromatography using an Ionpac CS12A analytical and Ionpac CG12A guard column for separation and 20mM methanesulfonic acid as eluent at a flowrate of 1 mL min^{-1} and injection volume of 25 µL (DIONEX ICS 1000). Dissolved organic nitrogen was estimated as TDN – (NH_4-N + NO_3-N).

Sample replicates, blanks, NIST (National Institute of Standards and Technology) traceable and check standards were run every 10th sample to monitor instrument precision and the co-efficient of variance among replicate samples.

2.2.5 Calculation of exports

Runoff discharge was delivered through a calibrated H-flume and measured with bubbler-type meters (Model 4230, Teledyne Isco, Inc., Lincoln, NE) at a 2 minute resolution. Data in liters runoff at a 2 minute resolution was summed for each runoff event for a total volume (L) runoff from each plot. Due to an interruption of flow meter readings from Block 1 in 2013 because of a lighting strike, runoff water volumes were modeled (Fontanier 2015).

2.2.6 Statistical analysis

Mean concentrations of DOC, DON, and cations were calculated for each plot for each runoff event. Total runoff volume for each plot for each runoff event were recorded. Mean concentrations for each plot and each event were multiplied by runoff volume to assess load leaving plot and divided by plot area to gain export (mg m^{-2} event $^{-1}$).

For each irrigation x fertilization treatment (n=3 per treatment) the mean concentrations for plot over the growing season were averaged; next the average for each treatment and standard deviation was calculated (n=3). A one-way analysis of variance (ANOVA) was performed on DON, DOC, and cations concentration as the independent variables and a treatment code as the independent variable i.e. year = 1 or 2, ET_o = 60, 45, or 30, and fertilization = 0, 2, or 4. So in year 1 a plot with an ET_o treatment of 60% and no fertilization would be coded 1600 (Table 2.6). Time series charts for exports of DOC, DON, and cations were created which included the baseline concentrations before treatments went into effect. To determine if there was a significant effect of deficit irrigation, fertilization or an interaction between deficit irrigation x fertilization, a univariate analysis of variance was performed (Table 2.7). Year of study, irrigation, and fertilization were the main independent factors and individual analytes were dependent factors. All statistical analysis was completed using SPSS v.22.0 (IBM Corp., Armonk, NY, USA).

2.3 Results

2.3.1 pH and electrical conductivity

Growing season pH of runoff solution ranged from 7.76±0.23 in the 30% x 4X fertilizer treatment to 7.93±0.03 in the treatment receiving 45% x 0X fertilizer treatment in 2013. (Fig. 2.5). In 2014 annual pH of runoff solution ranged from 7.33±0.23 to 7.59±0.05 in the treatment receiving 2X fertilizer and 30% irrigation and the treatment receiving 2X fertilizer and 60% irrigation (Fig. 2.5). Univariate analysis of variance determined that there was a significant effect of year ($p < 0.001$) on runoff pH values but no significant effect of irrigation or fertilization. Recoding each treatment type and performing an analysis of variance with post hoc Tukey test enabled significant differences among treatments for the two study years to be determined (Fig. 2.5).

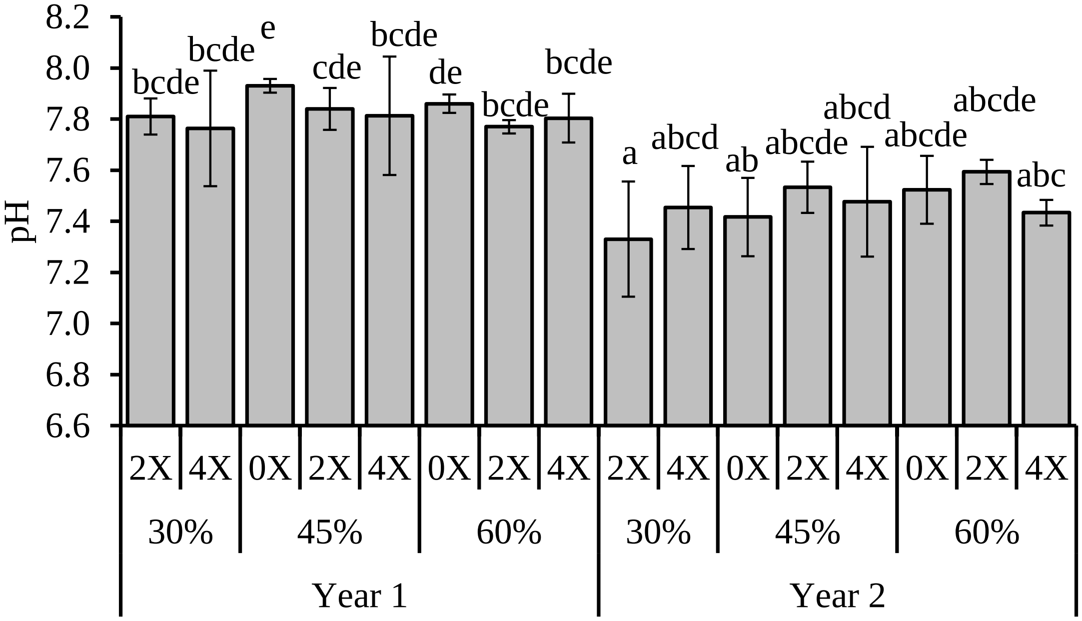


Fig. 2.5. Mean growing season pH in runoff water for 2013 (Year 1) and 2014 (Year 2). Error bars represent the standard deviation of three plots or treatments. Different lower case letters indicate significant differences among treatments.

Electrical conductivity of runoff solution ranged from 482±12 µS cm^{-1} in the 45% x 2X fertilized treatments to 582±0 µS cm^{-1} in the 60% x 0X fertilized treatments in 2013. In 2014, electrical conductivity ranged from 513±31 µS cm^{-1} in the 45% x 0X fertilized treatments to 617±67 µS cm^{-1} in the 60% x 2X fertilized treatments (Fig. 2.6). Univariate analysis of variance determined that there was a significant effect of year ($p < 0.05$) on electrical conductivity but analysis of variance determined there was no significant effect of treatment (Fig. 2.6).

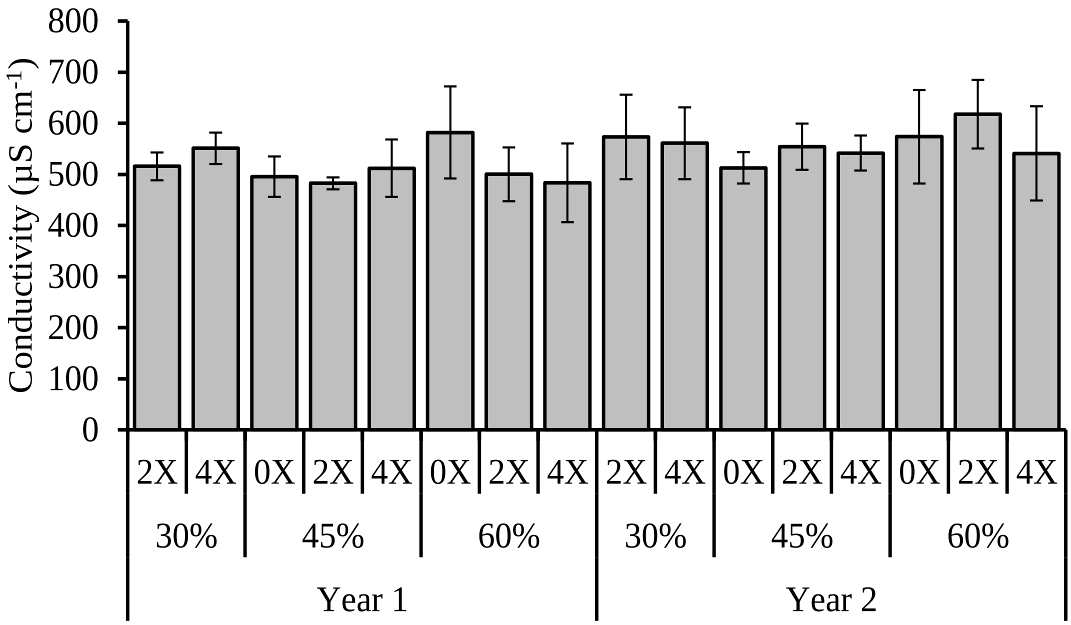


Fig. 2.6. Mean growing season electrical conductivity in runoff water for 2013 (Year 1) and 2014 (Year 2). Error bars represent standard deviation of three plot or treatments.

Table 2.6 ANOVA table of main effects on pH and EC. Bold values indicate significant effects at alpha < 0.05.

Main Effects		
	pH	EC
Year	**<0.001**	**0.039**
ET_o	0.383	0.186
STB	0.787	0.785

Table 2.7 ANOVA table of interaction effects on pH and EC

Interaction Effects		
	pH	EC
YEAR * ET_o	0.386	0.670
YEAR * STB	0.430	0.177
ET_o * STB	0.797	0.320
YEAR * ET_o * STB	0.403	0.910

2.3.2 DOC and DON

Growing season mean DOC concentrations of runoff solution ranged from 37.7±2.9 mg C L^{-1} in the 45% x 4X fertilizer treatment to 60.3±10.6 mg C L^{-1} in the treatment receiving 60% x 0X fertilizer treatment in 2013 (Fig. 2.7). In 2014 annual mean DOC concentration ranged from 27.7±1.9 mg C L^{-1} in 45% x 4X fertilizer treatment to 44.2±3.7 mg C L^{-1} in the treatment receiving 60% x 2X fertilizer treatment (Fig. 2.7). Univariate analysis of variance determined that there was a significant effect of year ($p < 0.001$) and irrigation rate ($p = 0.001$) on runoff DOC concentrations but no significant effect of fertilization. Recoding each treatment type and performing an analysis of variance with post hoc Tukey test enabled significant differences among treatments for the two study years to be determined (Fig. 2.7).

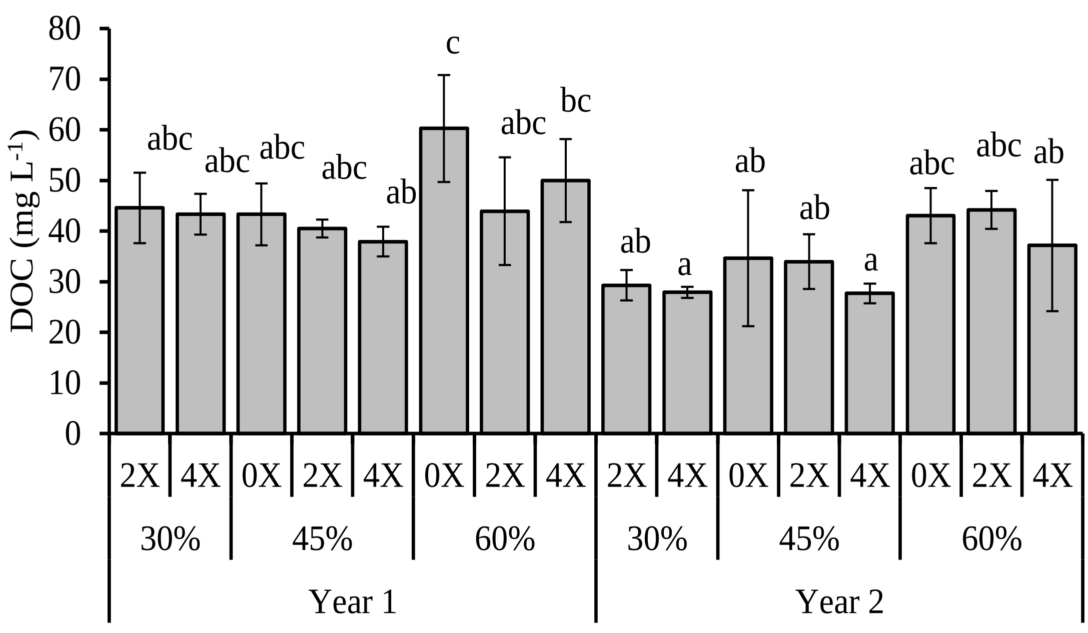


Fig. 2.7. Mean growing season concentrations of DOC in runoff water for 2013 (Year 1) and 2014 (Year 2). Error bars represent the standard deviation. Different lower case letters indicate significant differences among treatments.

Growing season mean DON concentrations of runoff solution ranged from 2.48±0.17 mg N L^{-1} in the 45% x 2X fertilizer treatment to 3.9±0.77 mg N L^{-1} in the 60% x 0X fertilizer treatment to in 2013 (Fig. 2.8). Annual mean DON concentration ranged from 1.83±0.83 mg N L^{-1} in the 45% x 0X fertilizer treatment to 3.22±0.60 mg N L^{-1} in the treatment receiving 60% x 4X fertilizer treatment in 2014 (Fig. 2.8). Univariate analysis of variance determined that there was significant effect of year ($p < 0.001$), irrigation ($p < 0.005$), and fertilization ($p < 0.05$) on runoff DON concentrations. Recording each treatment type and performing an analysis of variance with post hoc Tukey test enabled significant differences among treatments for the two study years to be determined (Fig. 2.8). There was a significant interaction between year and fertilizer treatment ($p < 0.001$) on mean growing season DON concentrations.

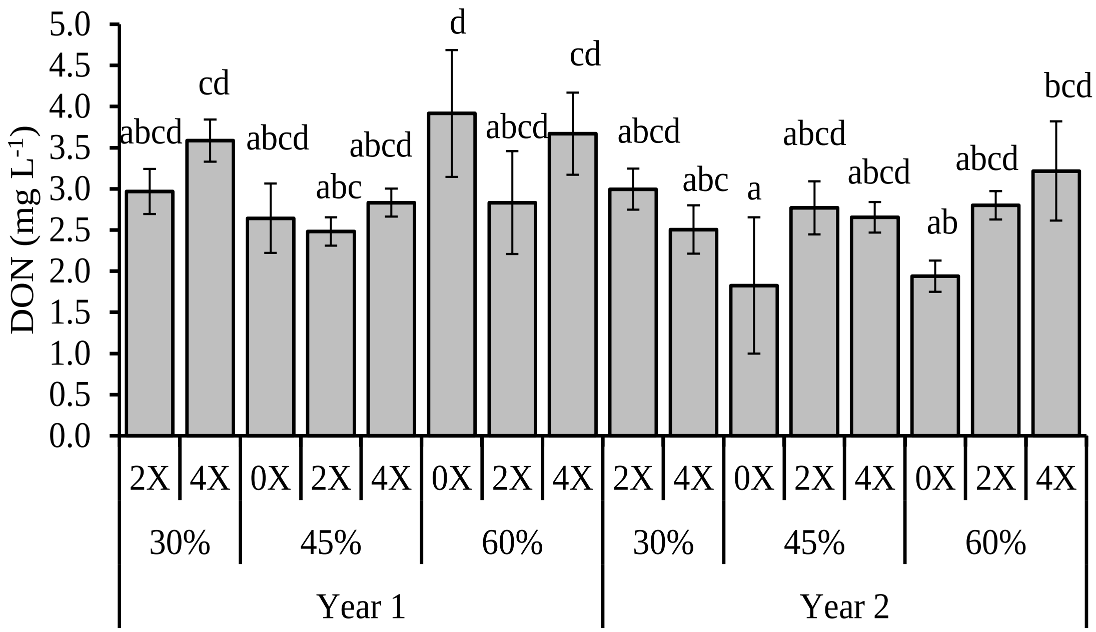


Fig. 2.8. Mean growing season concentrations of DON in runoff water for 2013 (Year 1) and 2014 (Year 2). Error bars represent the standard deviation. Different lower case letters indicate significant differences among treatments.

2.3.3 Orthophosphate-P

Growing season mean PO_4-P concentrations ranged from 4.84±0.86 mg L^{-1} in the 60% x 4X fertilization treatment to 5.96±0.47 mg L^{-1} in the treatment receiving 60% x 0X fertilization in 2013 (Fig. 2.9). In 2014 annual mean PO_4-P concentrations ranged from 2.16±0.39 mg L^{-1} in the 60% x 4X fertilizer to 2.77±0.50 mg L^{-1} in the treatment receiving 30% x 2X fertilization in 2014 (Fig. 2.9). Univariate analysis of variance determined that there was a significant effect of year and fertilization on runoff PO_4-P concentrations but no significant effect of irrigation. Recoding each treatment type and performing an analysis of variance with post hoc Tukey test enabled significant differences among treatments for the two study years to be determined (Fig. 2.9).

Overall, orthophosphate-P concentrations in runoff were significantly lower in 2014 for all treatments receiving 45% and 60% ET_o irrigation treatments (Fig. 2.9).

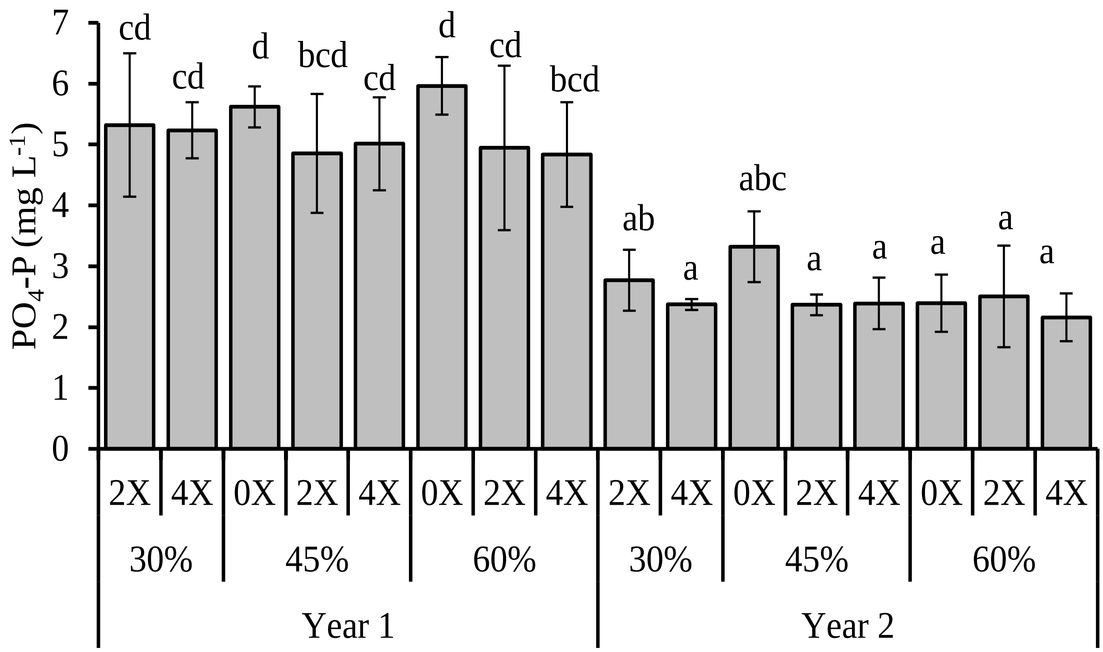


Fig. 2.9. Mean growing season concentrations of PO_4-P in runoff water for 2013 (Year 1) and 2014 (Year 2). Error bars represent the standard deviation. Different lower case letters indicate significant differences among treatments.

2.3.4 Cations

2.3.4.1 Sodium

Growing season sodium concentrations in runoff water ranged from 96±1 mg L^{-1} in the 45% x 2X fertilizer treatment to 123±15 mg L^{-1} in the 60% x 0X fertilizer treatment in 2013. In 2014 mean growing season sodium concentrations ranged from 39±3 mg L^{-1} in the 30% x 4X fertilizer treatment to 79±18 mg L^{-1} in the 60% x 2X fertilizer treatment. Univariate analysis of variance determined that year ($p < 0.001$) and irrigation rate (p = 0.001) had a significant effect on sodium concentrations. There were also significant interaction effects for year x irrigation rate (p = 0.021) and for year x fertilization application (p = 0.024). Analysis of variance with post hoc Tukey tests determined significant differences among year x treatment combinations (Fig. 2.10). Overall, sodium concentrations in runoff were significantly lower in 2014 for all treatments receiving 30% and 45% ETo irrigation treatments (Fig. 2.10).

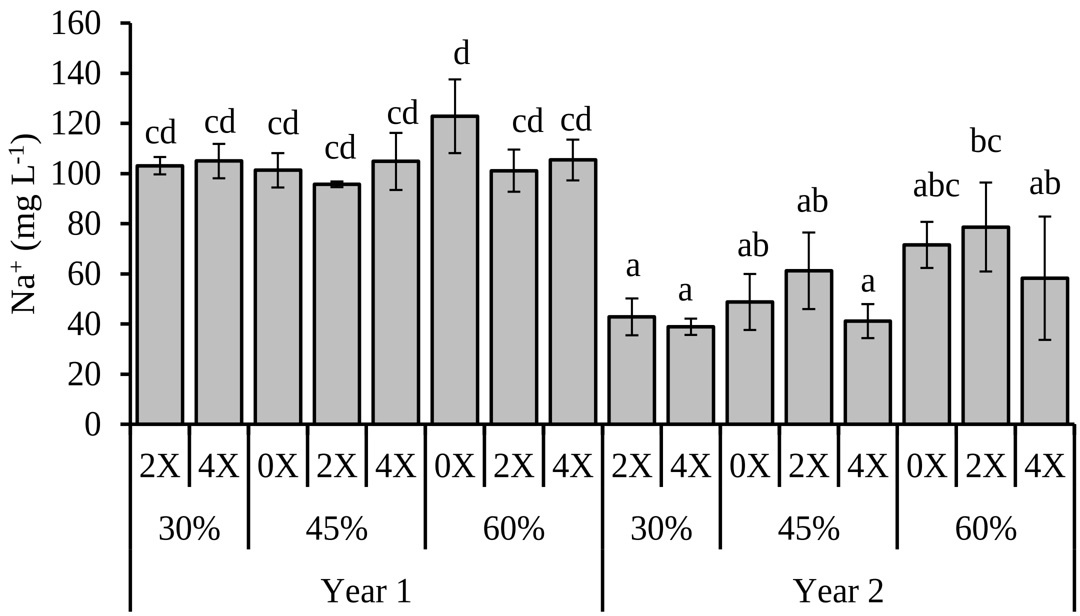


Fig. 2.10. Mean growing season concentrations of sodium in runoff water for 2013 (Year 1) and 2014 (Year 2). Error bars represent the standard deviation. Different lower case letters indicate significant differences among treatments.

2.3.4.2 Potassium

Growing season potassium concentrations in runoff water ranged from 17±1 mg L^{-1} in the 45% x 2X fertilizer treatment to 24±1 mg L^{-1} in the 30% x 4X fertilizer treatment in 2013. In 2014 mean growing season potassium concentrations ranged from

14±0 mg L^{-1} in the 60% x 0X fertilizer treatment to 16±1 mg L^{-1} in the 30% x 2X and 30% x 4X fertilizer treatments. Univariate analysis of variance determined that year ($p < 0.001$), irrigation rate ($p = 0.005$) and fertilization ($p = 0.048$) had a significant effect on potassium concentrations. There were no interaction on mean growing season potassium concentrations. Analysis of variance with post hoc Tukey tests determined significant differences among year x treatment combinations (Fig. 2.11). Overall, potassium concentrations in runoff tended to be lower in 2014 (Fig. 2.11).

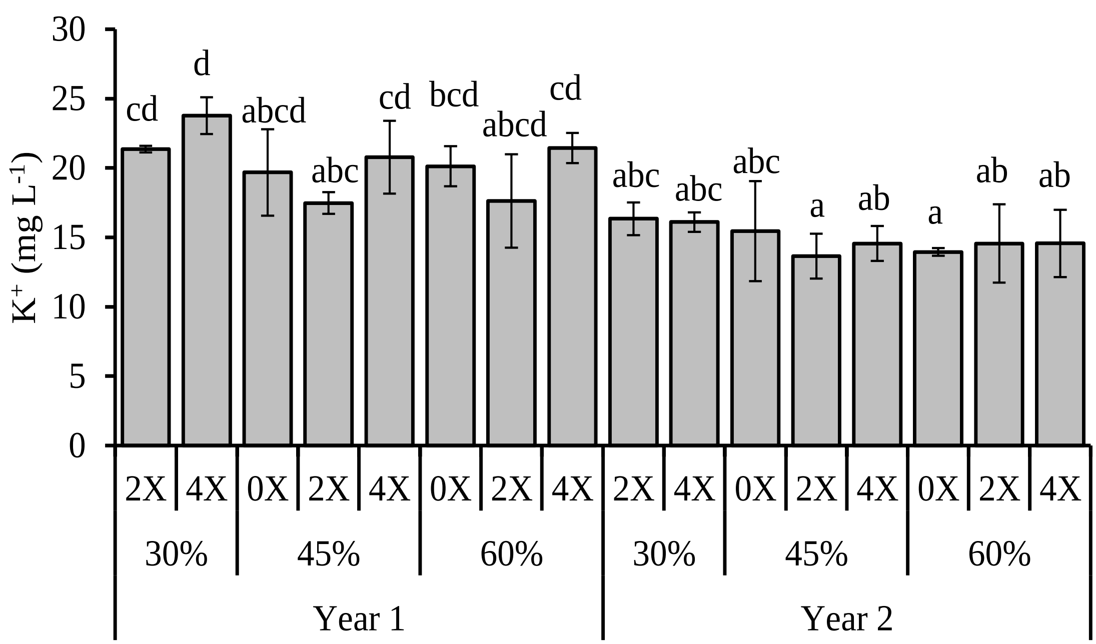


Fig. 2.11. Mean growing season concentrations of potassium in runoff water for 2013 (Year 1) and 2014 (Year 2). Error bars represent the standard deviation. Different lower case letters indicate significant differences among treatments.

2.3.4.3 Magnesium

Growing season magnesium concentrations in runoff water ranged from 1.09±0.21 mg L^{-1} in the 45% x 0X fertilizer treatment to 1.35±0.05 mg L^{-1} in the 30% x 4X fertilizer treatment in 2013. In 2014 mean growing season magnesium concentrations ranged from 4.36±0.86 mg L^{-1} in the 60% x 0X fertilizer treatment to 7.42±1.05 mg L^{-1} in the 30% x 2X treatment. Univariate analysis of variance determined that year ($p < 0.001$) and irrigation rate ($p < 0.001$) had a significant effect on magnesium concentrations. There was a significant interaction between year x irrigation rate ($p < 0.001$) on mean growing season magnesium concentrations. Analysis of variance with post hoc Tukey tests determined significant differences among year x treatment combinations (Fig. 2.12). Overall, magnesium concentrations in runoff were significantly lower in 2013 (Fig. 2.12).

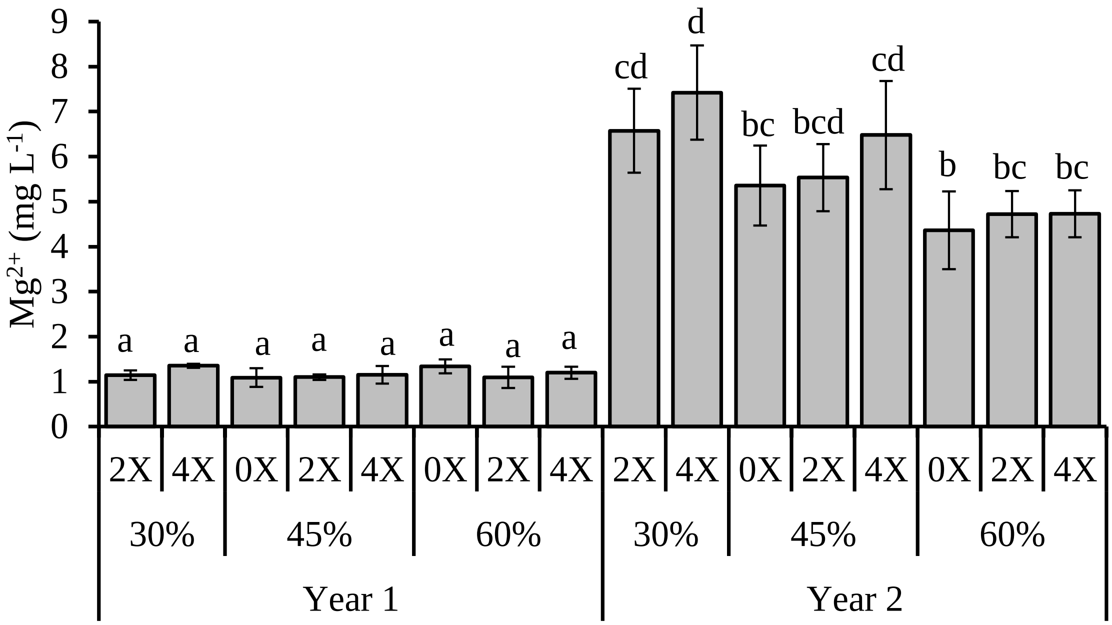


Fig. 2.12. Mean growing season concentrations of magnesium in runoff water for 2013 (Year 1) and 2014 (Year 2). Error bars represent the standard deviation. Different lower case letters indicate significant differences among treatments.

2.3.4.4 Calcium

Growing season calcium concentrations in runoff water ranged from 4.0±0.2 mg L^{-1} in the 45% x 2X fertilizer treatment to 5.3±0.7 mg L^{-1} in the 60% x 0X fertilizer treatment in 2013. In 2014 mean growing season calcium concentrations ranged from 48.2±1.3 mg L^{-1} in the 60% x 2X fertilizer treatment to 75.9±18.9 mg L^{-1} in the treatment receiving 30% x 4X fertilizer treatment. Univariate analysis of variance determined that year ($p < 0.001$) and irrigation ($p < 0.005$) had a significant effect on calcium concentrations (Table 2.8). There was a significant interaction between year x irrigation rate ($p < 0.005$) on mean growing season calcium concentrations. Analysis of variance with post hoc Tukey tests determined significant differences among year x treatment combinations (Table 2.9). Overall, calcium concentrations in runoff were significantly lower in 2013 (Fig. 2.13).

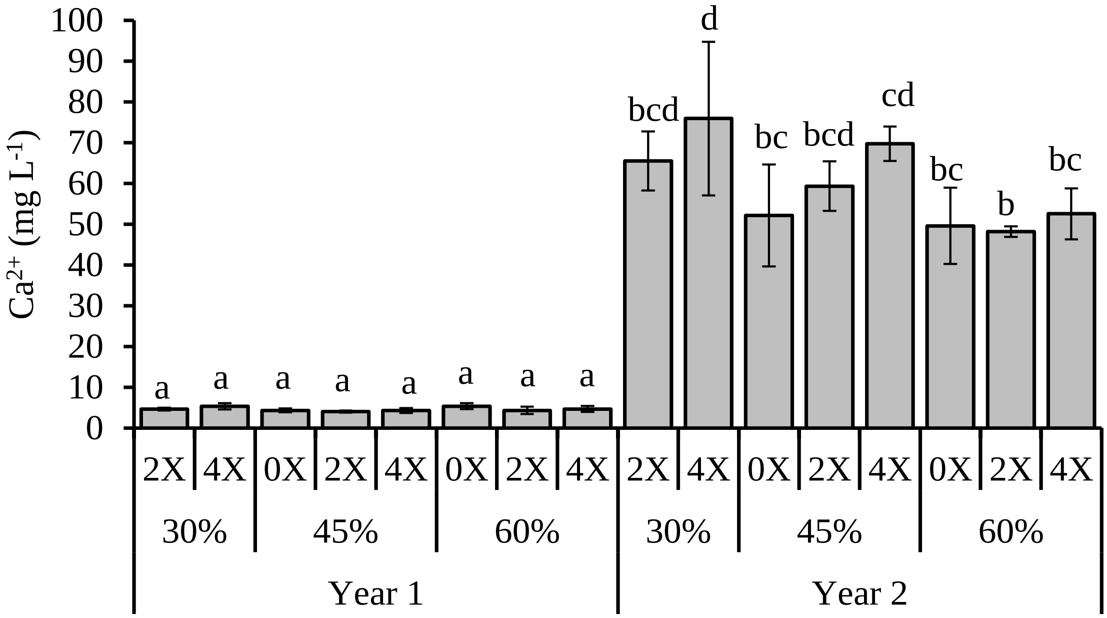


Fig. 2.13. Mean growing season concentrations of calcium in runoff water for 2013 (Year 1) and 2014 (Year 2). Error bars represent the standard deviation. Different lower case letters indicate significant differences among treatments.

Table 2.8 ANOVA table of main effects on analyte average concentrations. Bold values indicate significant effects at alpha < 0.05.

Main Effects							
	DOC	DON	PO_4	Na^+	K^+	Mg^{2+}	Ca^{2+}
Year	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
ET_o	**<0.001**	**0.003**	0.446	**0.001**	**0.005**	**<0.001**	**0.005**
STB	0.063	0.029	0.028	0.198	0.048	0.155	0.086

Table 2.9 ANOVA table of interaction effects on analyte average concentrations. Bold values indicate significant effects at alpha < 0.05.

	Main Effects						
	DOC	DON	PO_4	Na^+	K^+	Mg^{2+}	Ca^{2+}
Year	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
ET_o	**<0.001**	**0.003**	0.446	**0.001**	**0.005**	**<0.001**	**0.005**
STB	0.063	0.029	0.028	0.198	0.048	0.155	0.086

2.3.5 Time series of analytes exports

Times series become important when determining whether an application of fertilizer or other amendment is lost to runoff immediately after its addition during a rain event. Typically a time series of concentrations is examined but the importance of export (mg m^{-2}) is important because it also takes into account the volume of runoff (L) as well as the concentration in that runoff (mg L^{-1}) and normalizes the load to a per m^{-2} value (Figs. 2.14-2.20).

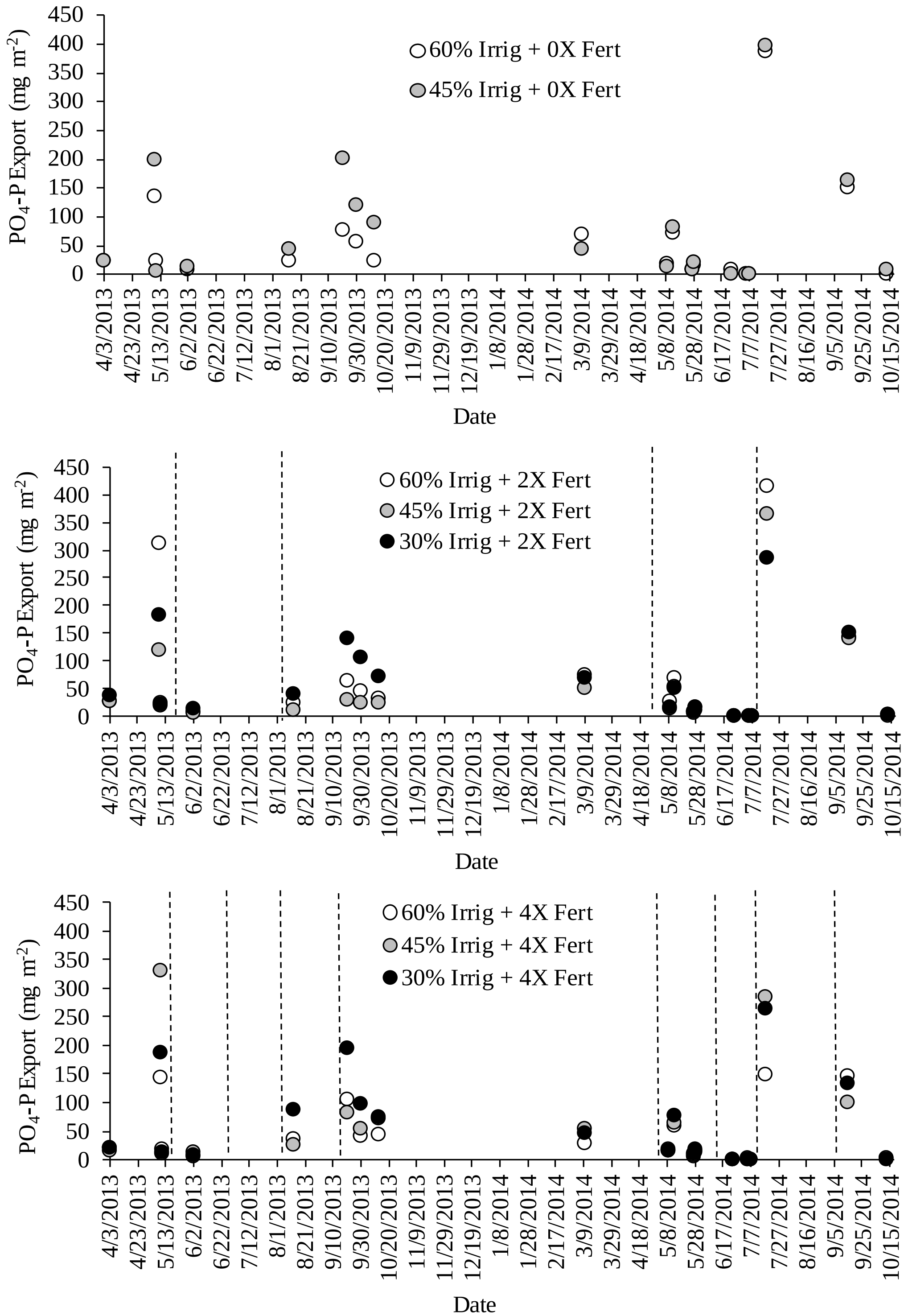


Fig. 2.14. Time series of exports of PO_4-P. Hatched lines indicate fertilizer addition.

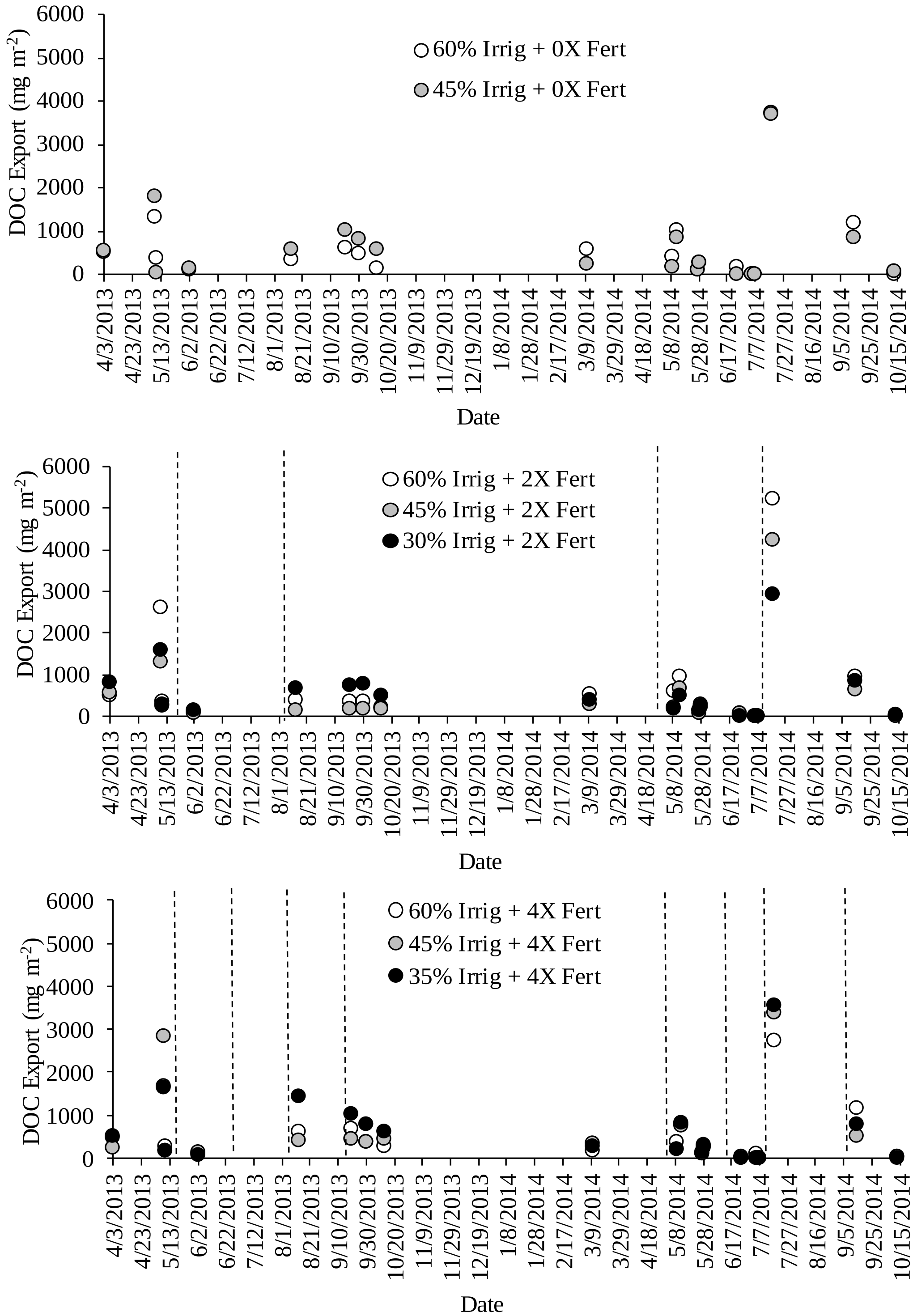


Fig. 2.15. Time series of DOC exports. Hatched lines indicate fertilizer addition

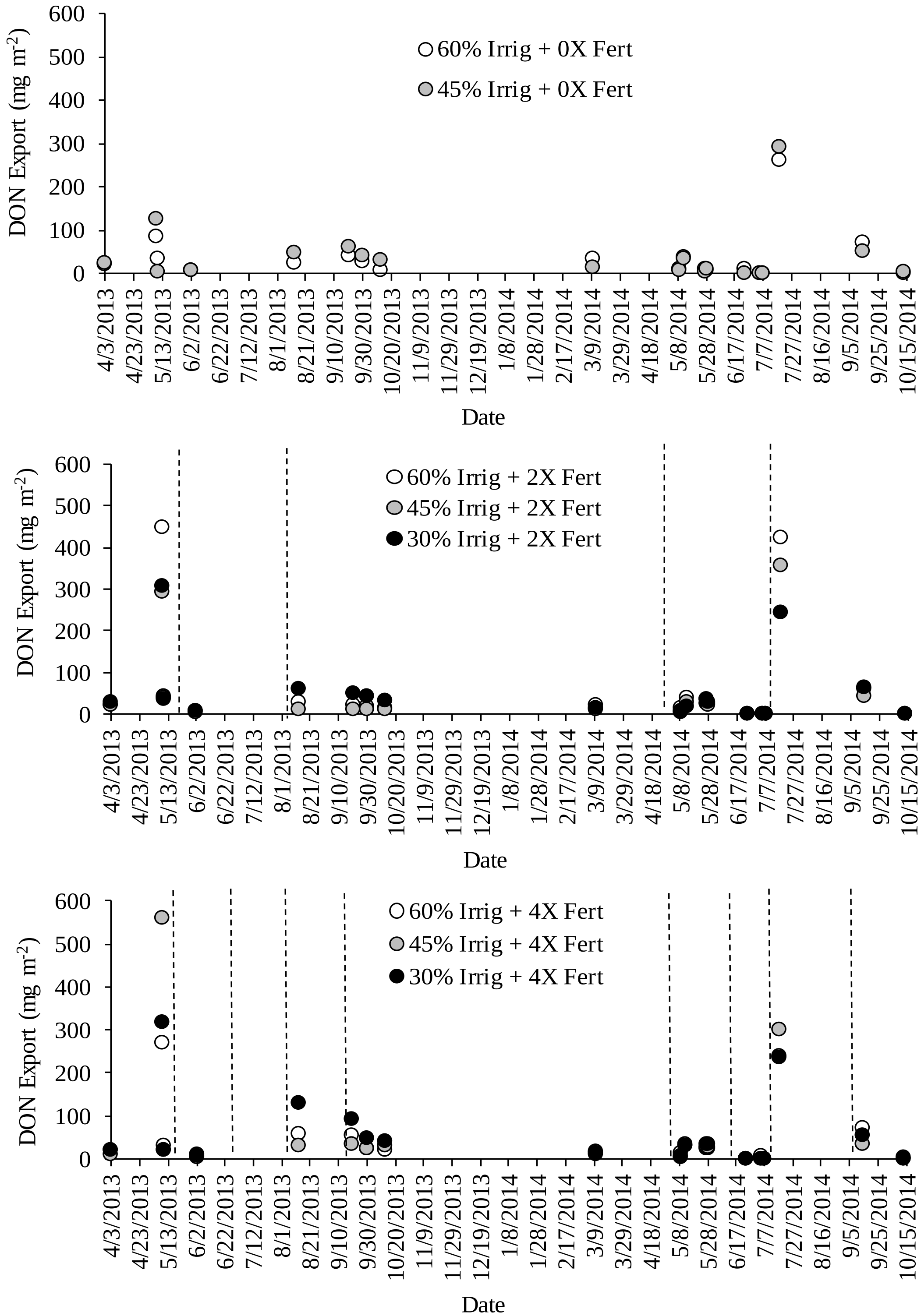


Fig. 2.16. Time series of DON exports. Hatched lines indicate fertilizer addition

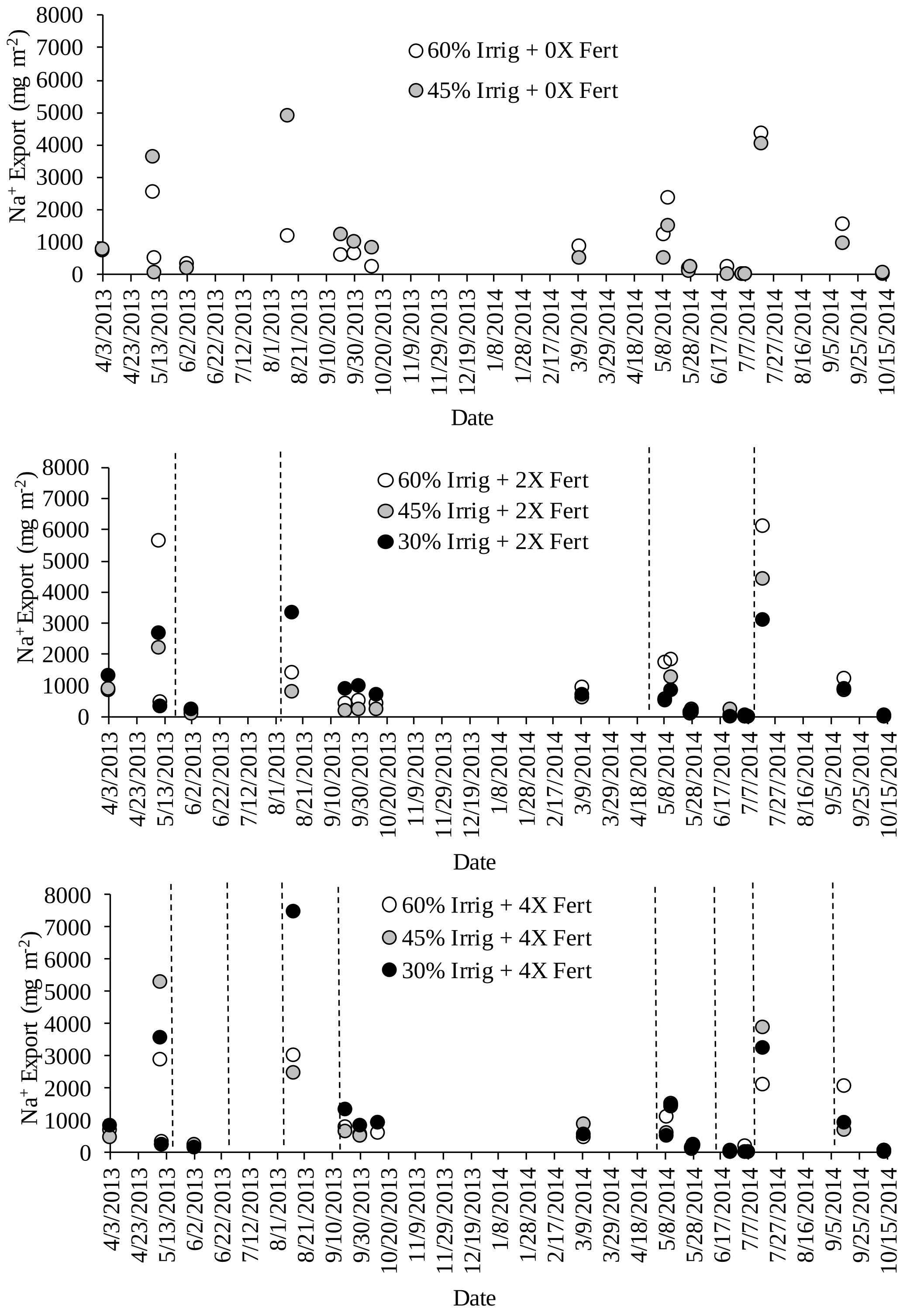


Fig. 2.17. Time series of Na^+ exports. Hatched lines indicate fertilizer addition

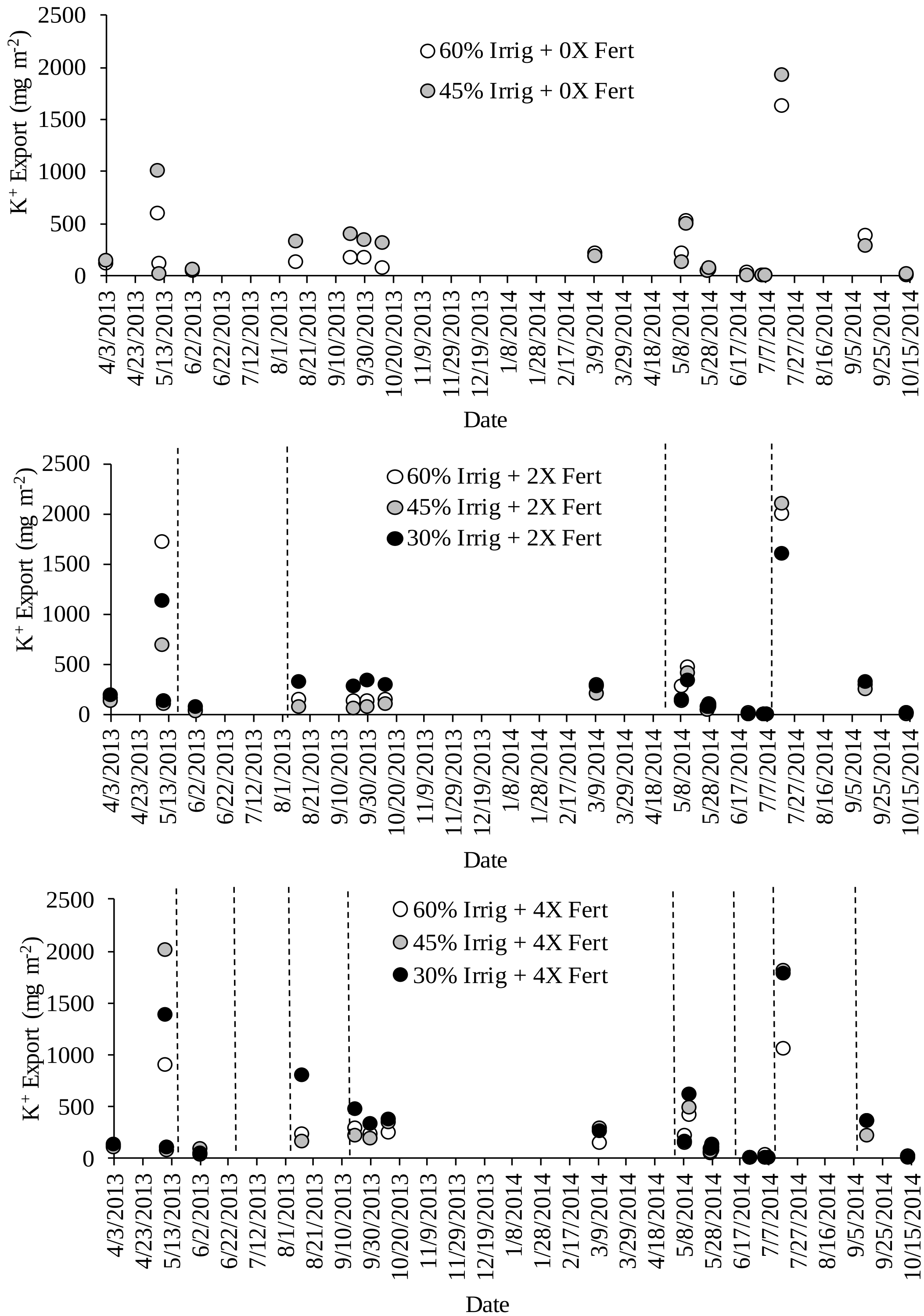


Fig. 2.18. Time series of K^+ exports. Hatched lines indicate fertilizer addition

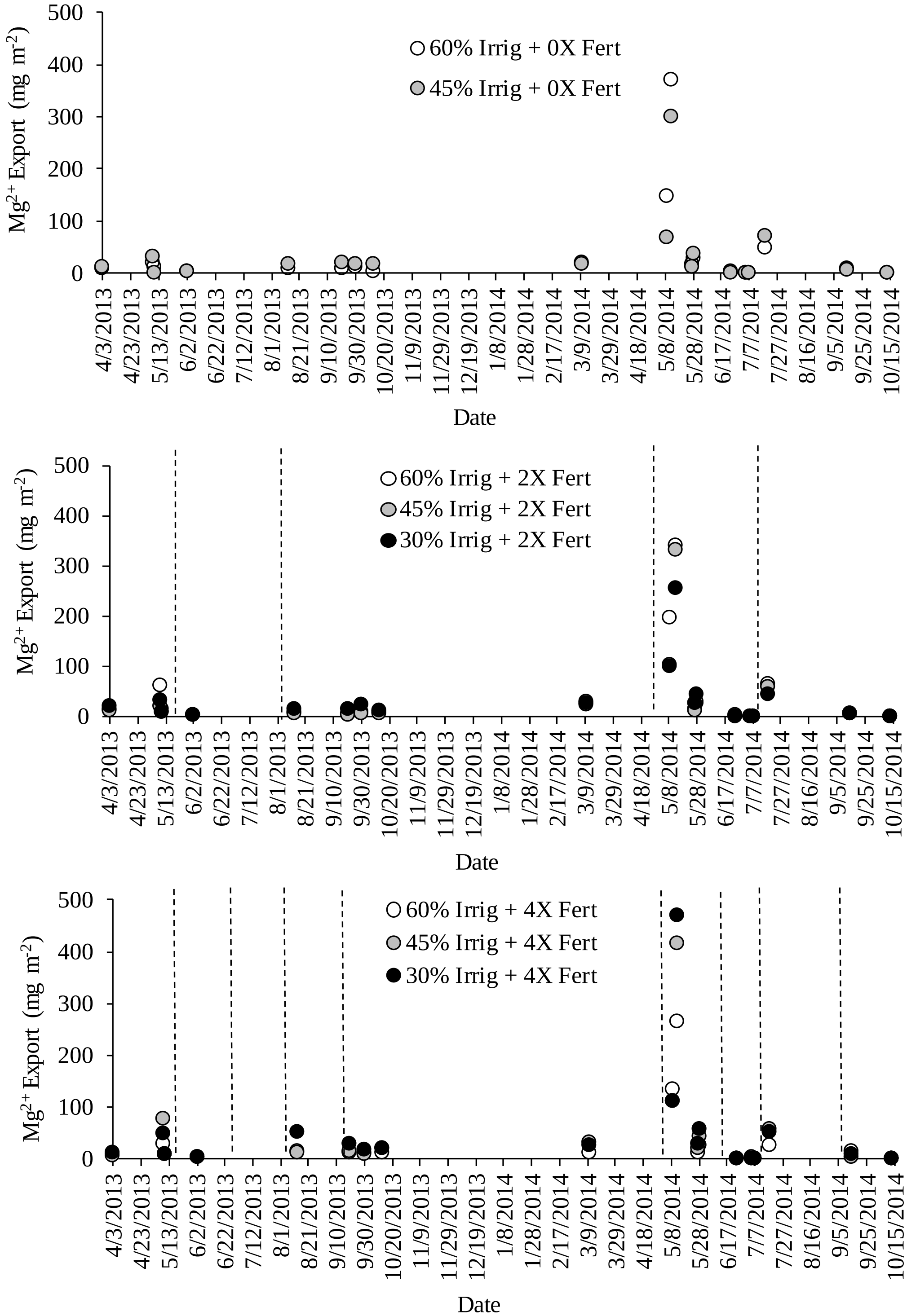


Fig. 2.19. Time series of Mg^{2+} exports. Hatched lines indicate fertilizer addition

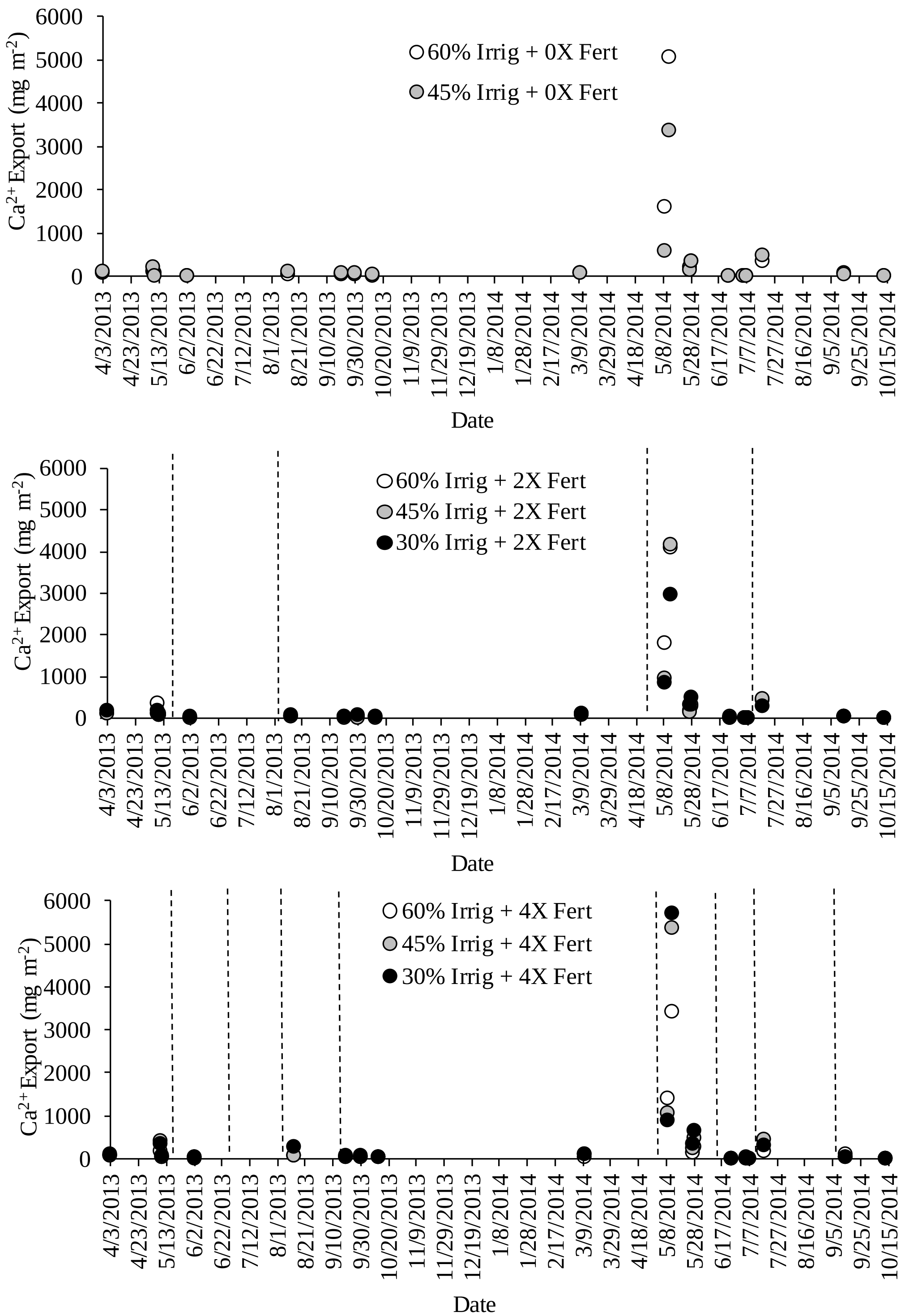


Fig. 2.20. Time series of Ca^{2+} exports. Hatched lines indicate fertilizer addition

2.4 Exports of analytes

Table 2.10 ANOVA table of main effects on export analytes. Bold values indicate significant effects at alpha < 0.05.

Main Effects							
	DOC	DON	PO_4-P	Na^+	K^+	Mg^{2+}	Ca^{2+}
Year	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
ET_o	0.210	0.324	0.446	**0.021**	0.901	0.763	0.761
STB	0.681	0.648	**0.028**	0.557	0.819	0.714	0.430

Table 2.11 ANOVA table of interaction effects on export analytes. Bold values indicate significant effects at alpha < 0.05.

Interaction Effects							
	DOC	DON	PO_4-P	Na^+	K^+	Mg^{2+}	Ca^{2+}
YEAR * ET_o	0.295	0.063	0.637	0.021	0.587	**<0.001**	**0.005**
YEAR * STB	0.295	**<0.001**	0.671	0.024	0.111	0.232	0.090
ET_o * STB	0.784	0.310	0.878	0.433	0.834	0.702	0.575
YEAR * ET_o * STB	0.512	0.384	0.654	0.492	0.879	0.797	0.653

2.4.1 DOC and DON

Growing season DOC exports ranged from 1121±604 mg C m^{-2} in the 45% x 4X fertilizer treatment to 3094±2636 mg C m^{-2} in the 60% x 0X fertilizer treatment in 2013. In 2014 annual mean DOC exports ranged from 4869±2233 mg C m^{-2} in the 30% x 2X fertilizer treatment to 8197±4543 mg C m^{-2} in the treatment receiving 60% x 2X fertilizer treatment. Univariate analysis of variance determined that there was a significant effect of year ($p < 0.001$) on runoff DOC exports but no significant effect of irrigation or fertilization (Table 2.10). Recoding each treatment type and performing an analysis of variance with post hoc Tukey test enabled significant differences among treatments for the two years to be determined (Fig. 2.21).

DON exports ranged from 93.3±50 mg N m^{-2} in the 45% x 0X fertilizer treatment to 202.3±174 mg N m^{-2} in the treatment receiving 60% x 0X fertilizer treatment in 2013. The DON exports ranged from 394±172 mg N m^{-2} in the 30% x 2X fertilizer treatment to 598±364 mg N m^{-2} in the 60% x 2X fertilizer treatment in 2014. Univariate analysis of variance determined that there was a signification effect of year ($p < 0.001$) on runoff DON exports but no significant effect of irrigation or fertilization. Recoding each treatment type and performing an analysis of variance with post hoc Tukey test enabled significant differences among treatments for the two years to be determined (Fig. 2.22; Table 2.11)

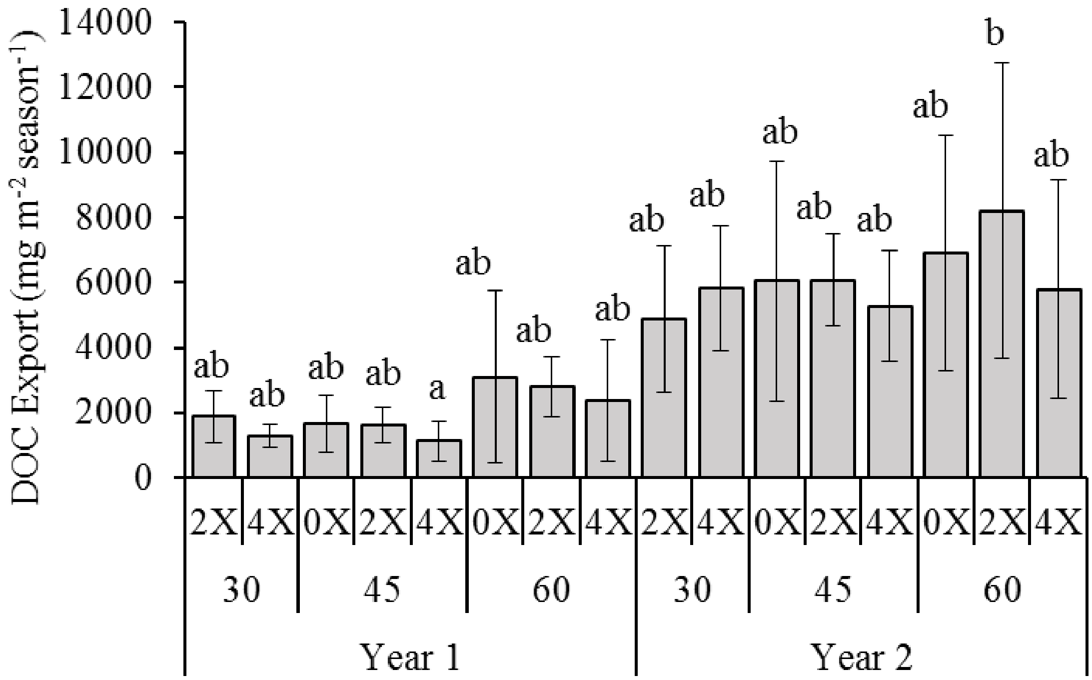


Fig. 2.21. Mean growing season dissolved organic carbon exports in runoff water for 2013 (Year 1) and 2014 (Year 2). Error bars represent the standard deviation. Different lower case letters show significant differences among treatments.

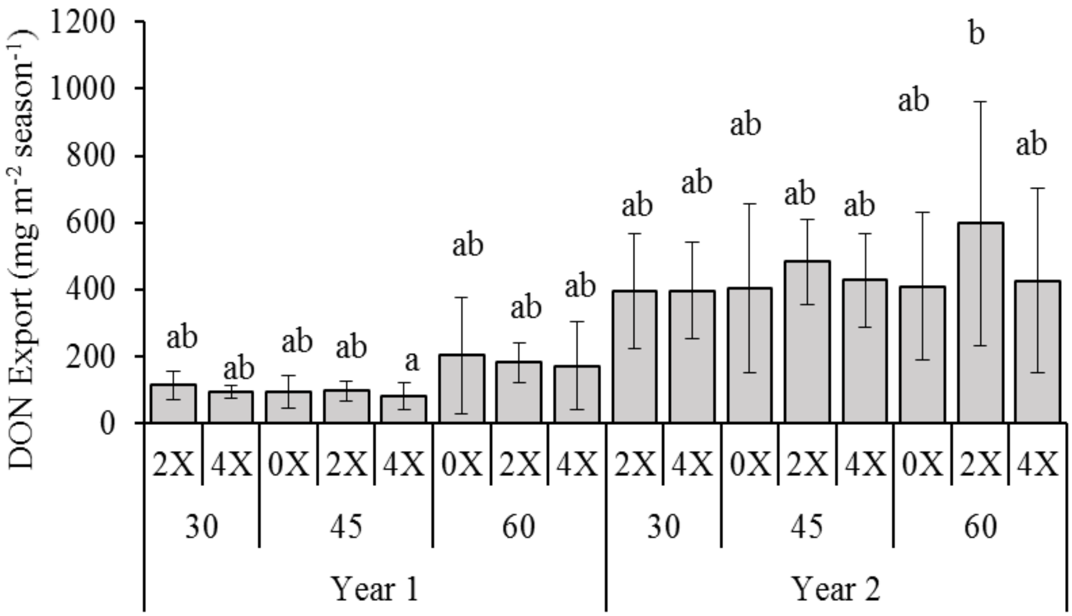


Fig. 2.22. Mean growing season dissolved organic nitrogen exports in runoff water for 2013 (Year 1) and 2014 (Year 2). Error bars represent the standard deviation. Different lower case letters show significant differences among treatments.

2.4.2 Orthophosphate-P

Growing season PO_4-P exports in runoff water ranged from 174.7±28.1 mg m^{-2} in the 30% x 4X fertilizer treatment to 387±144.4 mg m^{-2} in the 60% x 2X fertilizer treatment in 2013. In 2014 PO_4-P exports ranged from 400.3±118 mg m^{-2} in 60% x 4X fertilizer treatment to 694.3±364 mg m^{-2} in the treatment receiving 45% x 0X fertilizer treatment. Univariate analysis of variance determined that year ($p < 0.001$) had a significant effect on orthophosphate exports but no significant effect of fertilizer and irrigation. Recoding each treatment type and performing an analysis of variance with post hoc Tukey test enabled significant differences among treatments for the two years to be determined (Fig. 2.23)

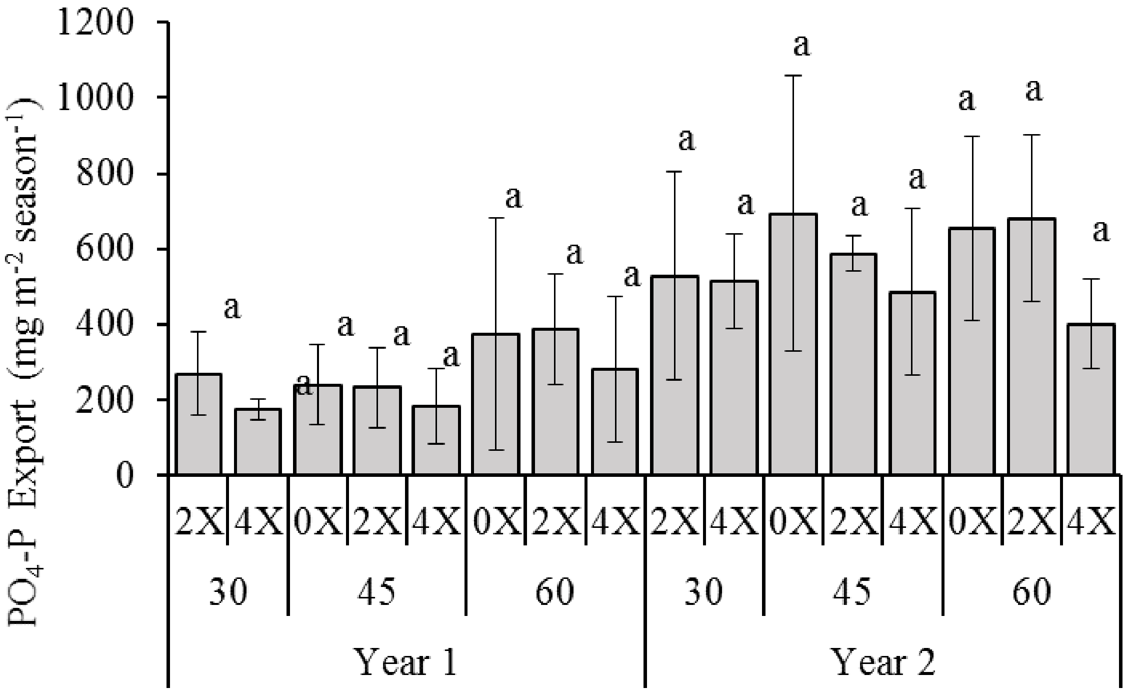


Fig. 2.23. Mean growing season orthophosphate-P exports in runoff water for 2013 (Year 1) and 2014 (Year 2). Error bars represent the standard deviation. Different lower case letters show significant differences among treatments.

2.4.3 Sodium

Growing season sodium exports in runoff water ranged from 1809±345 mg m^{-2} in the 30% x 4X fertilizer treatment to 5285±1413 mg m^{-2} in the 60% x 2X fertilizer treatment in 2013. In 2014 sodium exports ranged from 5684±2881 mg m^{-2} in the 30% x 2X fertilizer treatment to 11465±5523 mg m^{-2} in the treatment receiving 60% x 2X fertilizer treatment. Sodium had the highest mean exports of 11465.3± 6733 mg m^{-2} during 2014 with 60% ET_o and 4X fertilizer applications that year. The lowest mean exports were 1809.3±345.8, 2081.3± 1068.7, and 2180.3±1044.6 mg m^{-2} during 2013 with 30% ET_o and 4X, 45 ET_o and 4X, 45 ET_o and 0X, respectively (Fig. 2.24). Univariate analysis of variance determined that year ($p < 0.001$) and irrigation ($p < 0.05$)

had a significant effect on sodium exports. There were no interaction effects on mean growing season sodium exports. Analysis of variance with post hoc Tukey tests determined significant differences among year x treatment combinations.

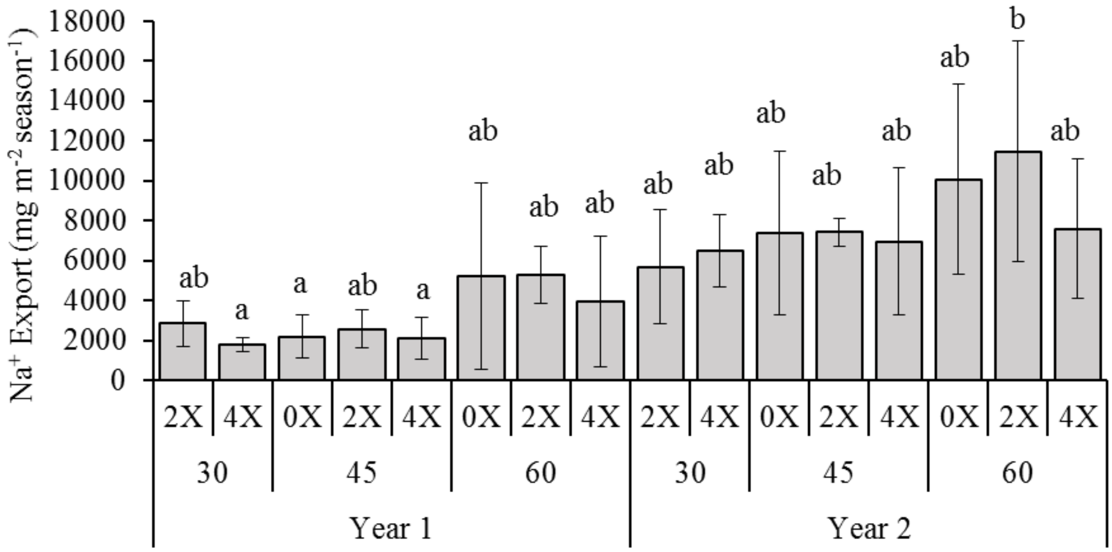


Fig. 2.24. Mean growing season sodium exports in runoff water for 2013 (Year 1) and 2014 (Year 2). Error bars represent the standard deviation. Different lower case letters show significant differences among treatments.

2.4.4 Potassium

Growing season potassium exports in runoff water ranged from 713±332 mg m^{-2} in the 45% x 4X fertilizer treatment to 1330±377 mg m^{-2} in the 60% x 2X fertilizer treatment in 2013. In 2014 potassium exports ranged from 2252±1343 mg m^{-2} in the 60% x 4X fertilizer treatment to 3215±1148 mg m^{-2} in the treatment receiving 60% x 2X fertilizer treatment. Univariate analysis of variance determined that year ($p < 0.001$) had a significant effect on potassium exports but irrigation rate and fertilizer did not. There were no interaction effects on mean growing season potassium exports. Analysis of variance with post hoc Tukey test determined significant differences among year x treatment combinations (Fig. 2.25).

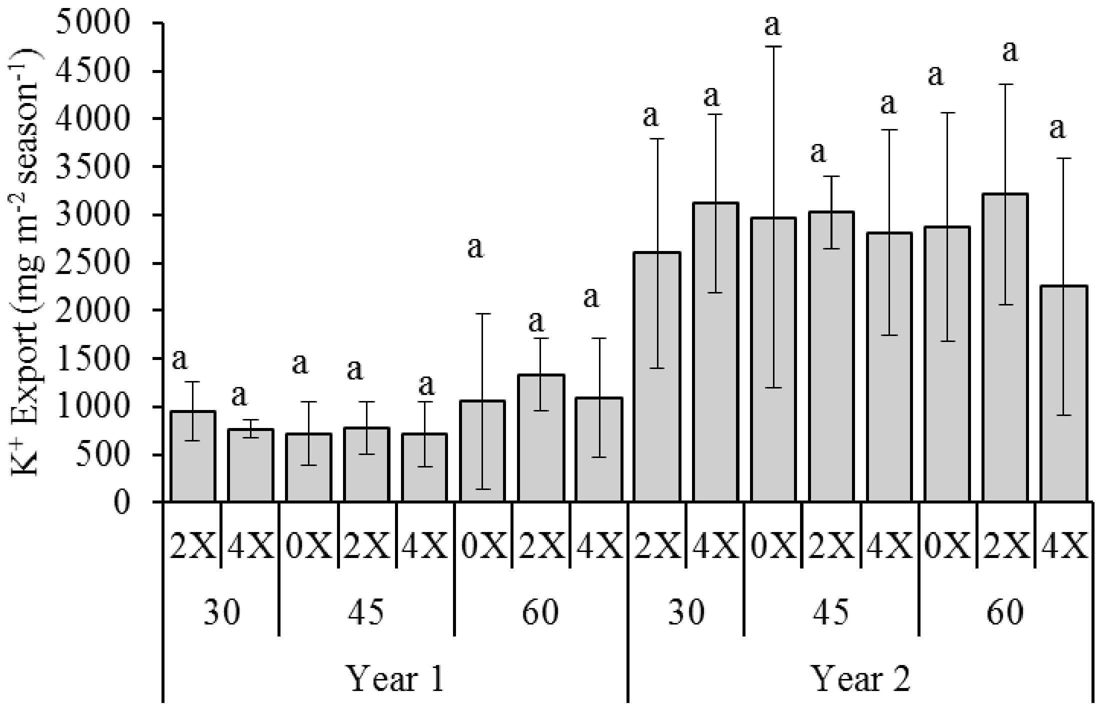


Fig. 2.25. Mean growing season potassium exports in runoff water for 2013 (Year 1) and 2014 (Year 2). Error bars represent the standard deviation. Different lower case letters show significant differences among treatments.

2.4.5 Magnesium

Growing season magnesium exports in runoff water ranged from 40±18 mg m^{-2} in the 45% x 0X fertilizer treatment to 76±21 mg m^{-2} in the 60% x 2X fertilizer treatment in 2013. In 2014 mean growing season magnesium exports ranged from 477±255 mg m^{-2} in the 30% x 2X fertilization treatment to 726±35 mg m^{-2} in 30% x 4X fertilizer treatment. Univariate analysis of variance determined that year ($p < 0.001$) had a significant effect on magnesium exports. There were no interaction effects on mean growing season magnesium exports. Analysis of variance with post hoc Tukey test determined significant differences among year x treatment combinations. Overall, magnesium exports in runoff were significantly lower in 2013 (Fig. 2.26).

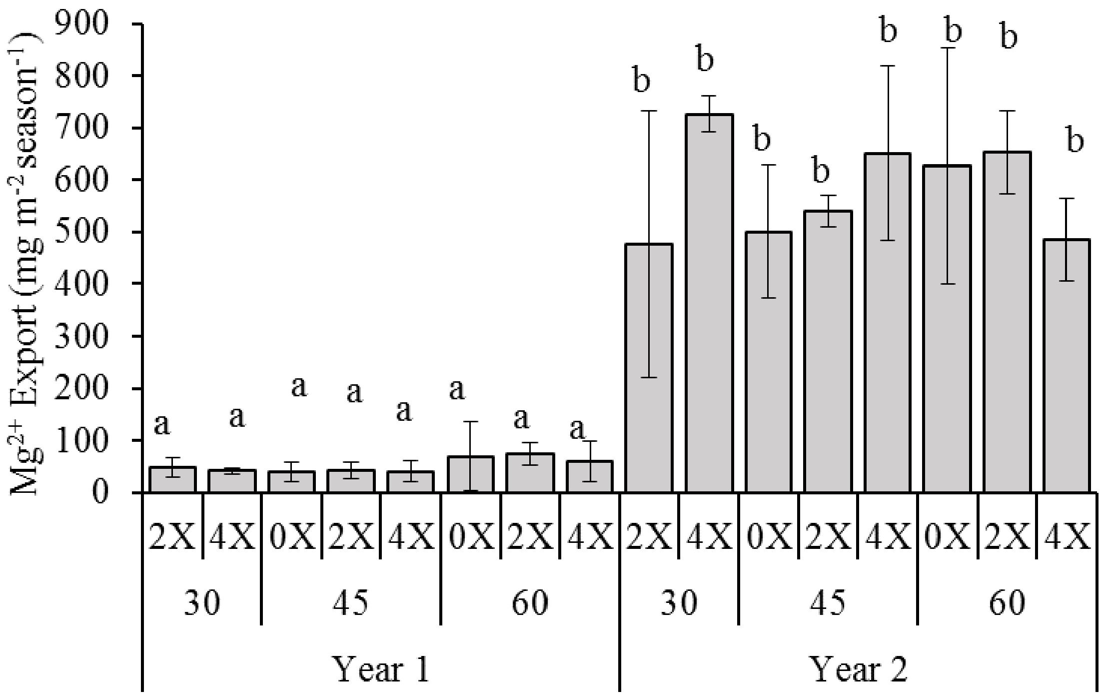


Fig. 2.26. Mean growing season magnesium exports in runoff water for 2013 (Year 1) and 2014 (Year 2). Error bars represent the standard deviation. Different lower case letters show significant differences among treatments.

2.4.6 Calcium

Growing season magnesium exports in runoff water ranged from 156±54 mg m^{-2} in the 30% x 2X fertilizer treatment to 248±79 mg m^{-2} in the 60% x 2X fertilizer treatment in 2013. In 2014 mean growing season magnesium exports ranged from 4902±2579 mg m^{-2} in the 30% x 2X fertilization treatment to 7913±1302 mg m^{-2} in 30%

x 4X fertilizer treatment. Univariate analysis of variance determined that year ($p < 0.001$) had a significant effect on magnesium exports. There was a significant interaction between irrigation x fertilizer ($p = 0.05$) on mean growing season calcium exports. Analysis of variance with post hoc Tukey test determined significant differences among year x treatment combinations. Overall, calcium exports in runoff were significantly lower in 2013 (Fig. 2.27).

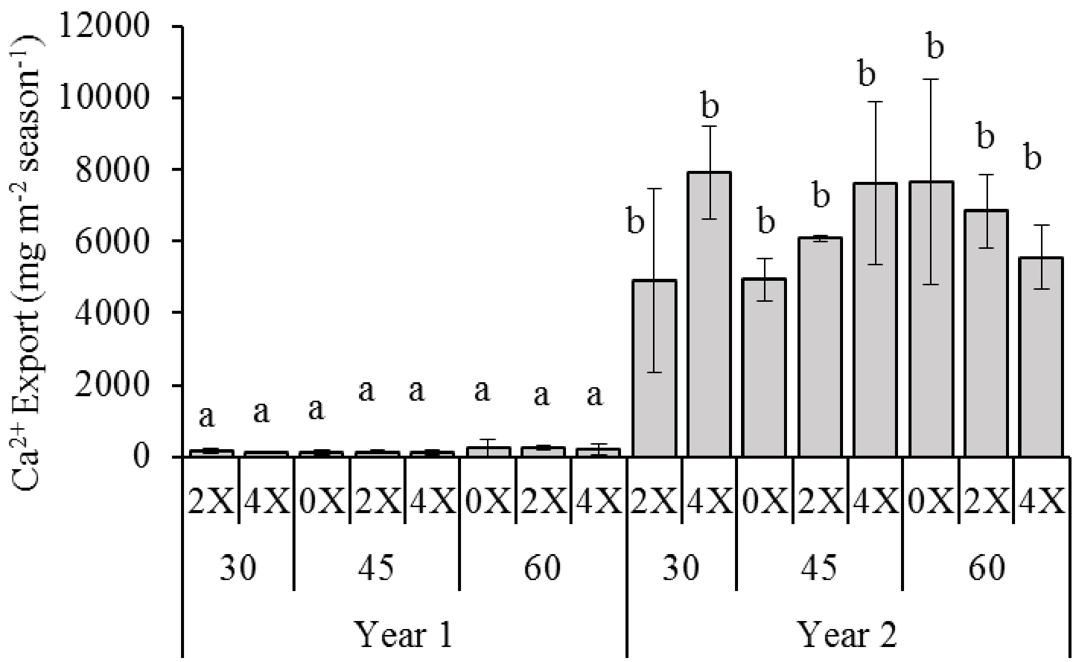


Fig. 2.27. Mean growing season calcium exports in runoff water for 2013 (Year 1) and 2014 (Year 2). Error bars represent the standard deviation. Different lower case letters show significant differences among treatments.

2.5 Relationships among anion and cation exports

2.5.1 Relationship between DOC export and cation exports

There were strong and significant relationships between DOC export and sodium export. In Year 1 sodium export explained 97% of the variance in DOC export ($p < 0.001$) and 88% of the variance in DOC export in Year 2 ($p < 0.0001$; Fig. 2.28A). Strong and significant relationships also occurred between DOC export and potassium export in both years. In Year 1 potassium export explained 88% and Year 2 80% of the variance in DOC export ($p < 0.001$; Fig. 2.28B). There were strong and significant relationships between DOC export and both magnesium and calcium export in Year 1 only ($R^2 = 0.93$ and $R^2 = 0.98$; $p < 0.001$; Figs. 2.28C and 2.28D). These relationships, although significant were very weak in Year 2 of the study ($R^2 = 0.23$ and $R^2 = 0.21$; $p < 0.05$; Figs. 2.28C and 2.28D).

2.5.2 Relationship between DON export and cation exports

There were strong and significant relationships between DON export and sodium export. In Year 1 sodium export explained 96% of the variance in DON export ($p < 0.001$) and 75% of the variance in DON export in Year 2 ($p < 0.0001$; Fig. 2.29A). Strong and significant relationships also occurred between DON export and potassium export in both years. In Year 1 potassium export explained 90% and Year 2 75% of the variance in DON export ($p < 0.001$; Fig. 2.29B). There were strong and significant relationships between DON export and both magnesium and calcium export in Year 1 only ($R^2 = 0.94$ and $R^2 = 0.96$; $p < 0.001$; Figs. 29C and 29D). These relationships, only significant for magnesium were very weak in Year 2 of the study ($R^2 = 0.17$ and $R^2 = 0.15$; Figs. 2.29C and 2.29D).

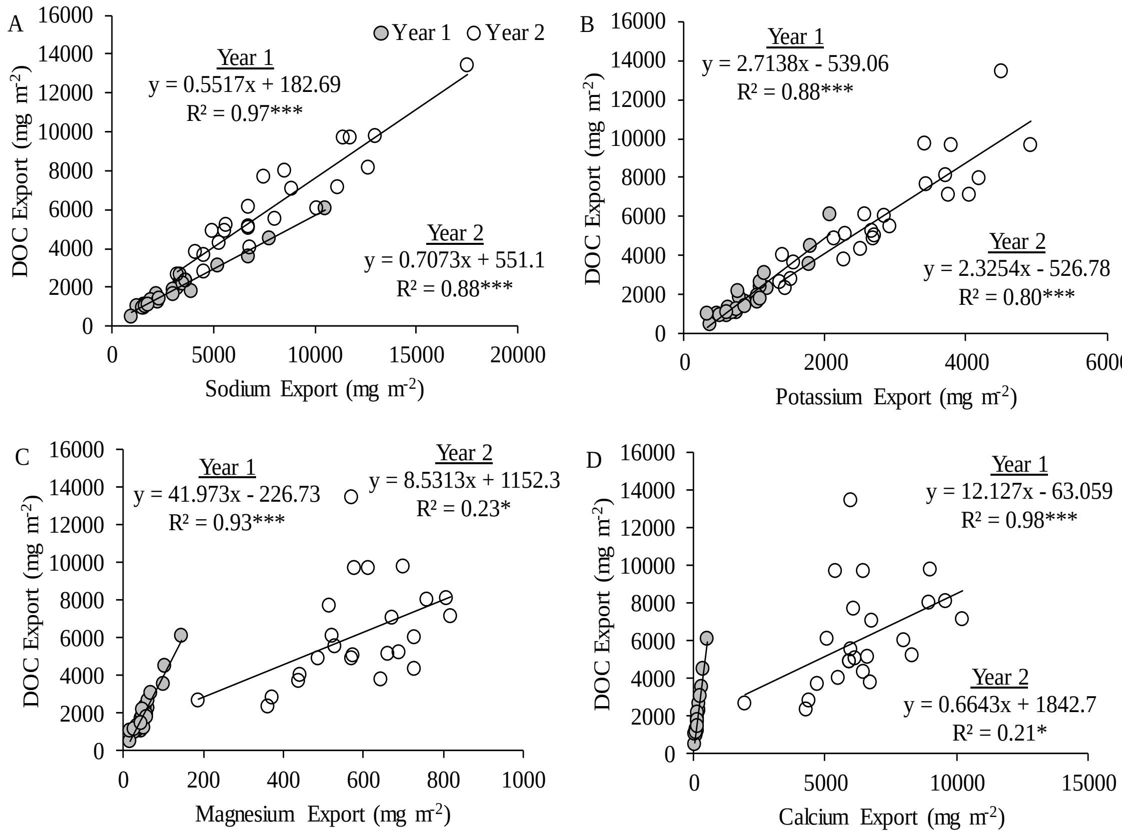
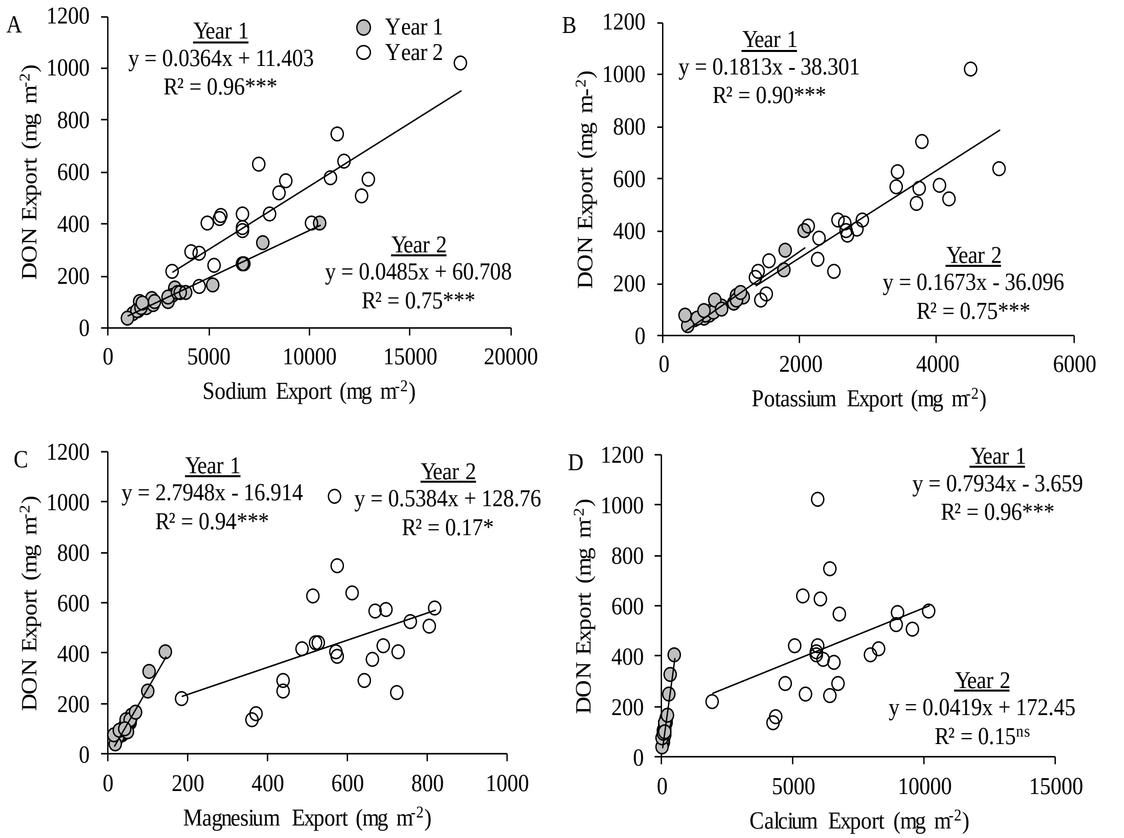


Fig. 2.28. Relationships between DOC export and A) sodium export, B) potassium export, C) magnesium export and D) calcium export. ***significant at $p < 0.001$ and *significant at $p < 0.05$.

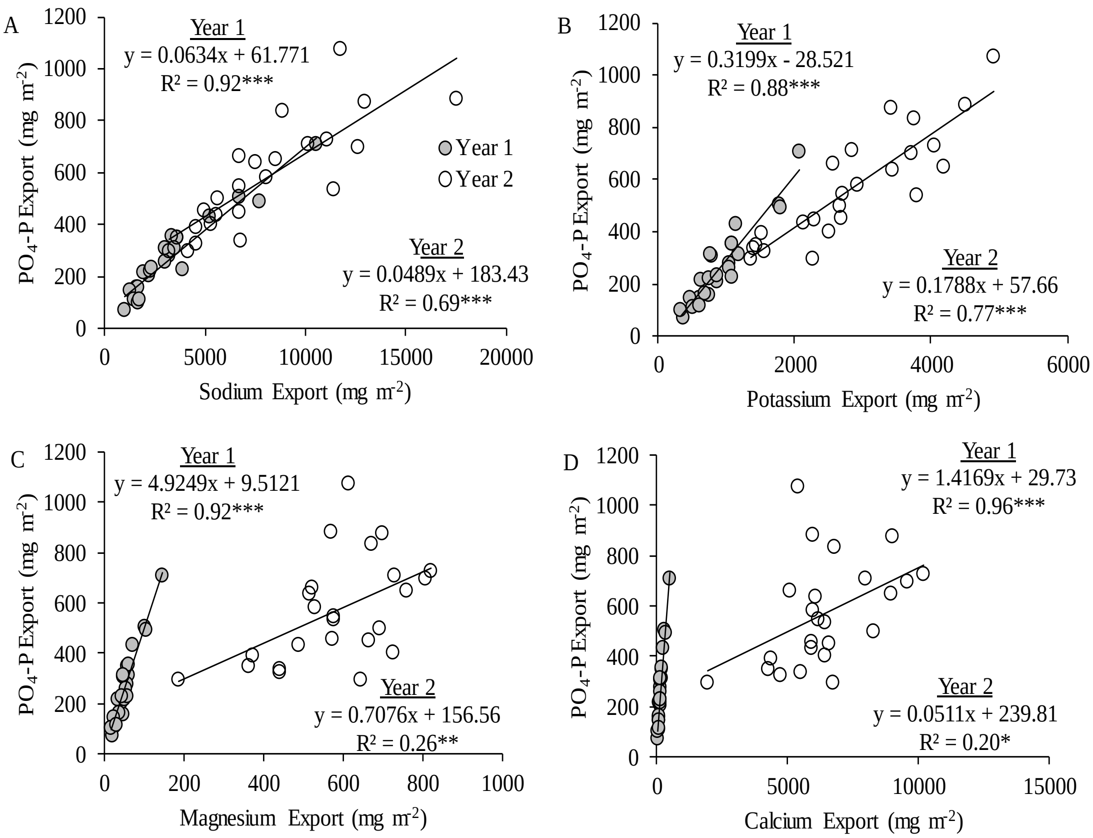


2.29. Relationships between DON export and A) sodium export, B) potassium export, C) magnesium export and D) calcium export. ***significant at $p < 0.001$ and *significant at $p < 0.05$.

2.5.3 Relationship between PO_4-P export and cation exports

There were strong and significant relationships between PO_4-P export and sodium export. In Year 1 sodium export explained 92% of the variance in PO_4-P export ($p < 0.001$) and 69% of the variance in PO_4-P in Year 2 ($p < 0.001$; Fig. 2.30A). Strong and significant relationships also occurred between PO_4-P and potassium in both years. In Year 1 potassium export explained 88% and Year 2 77% of the variance in PO_4-P export ($p < 0.001$; Fig. 2.30B). There were strong and significant relationships between PO_4-P export and both magnesium and calcium in Year 1 only ($R^2 = 0.92$ and $R^2 = 0.96$;

p < 0.001; Figs. 2.30C and 2.30D). These relationships, although significant were very weak in Year 2 of the study (R^2 = 0.26 and R^2 = 0.20; $p < 0.01$ and $p < 0.05$; Figs. 2.30C and 2.30D).

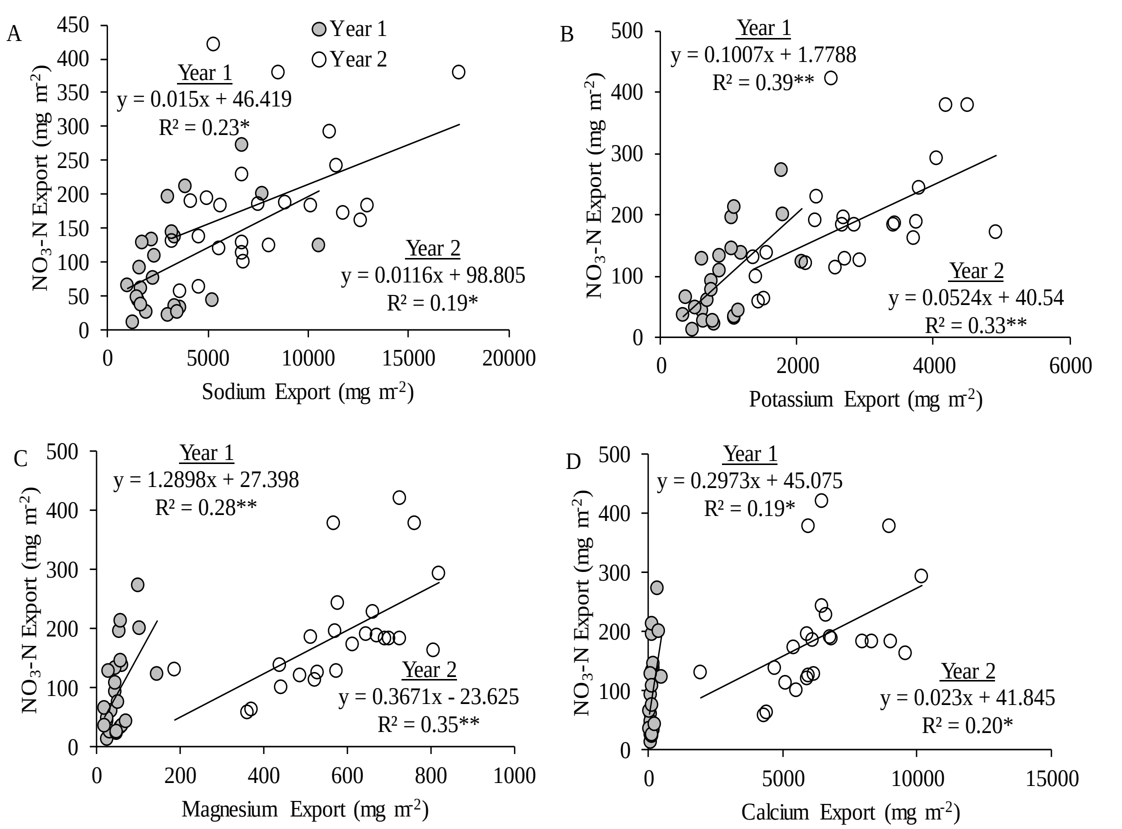


2.30. Relationships between PO_4-P export and A) sodium export, B) potassium export, C) magnesium export and D) calcium export. ***significant at $p < 0.001$, ** significant at $p < 0.01$ and *significant at $p < 0.05$.

2.5.4 Relationship between NO_3-N export and cation exports

There were significant but very weak relationships between NO_3-N export and sodium export. In Year 1 sodium export explained 23% of the variance in NO_3-N export ($p < 0.05$) and 19% of the variance in NO_3-N export in Year 2 ($p < 0.05$; Fig. 2.31A).

Significant but very weak relationships also occurred between NO_3-N export and potassium export in both years. In Year 1 potassium export explained 39% and Year 2 33% of the variance in NO_3-N export ($p < 0.01$; Fig. 2.31B). There were significant but very weak relationships between NO_3-N exports and both magnesium and calcium export in Year 1 ($R^2 = 0.28$ and $R^2 = 0.19$; $p < 0.01$ and $p < 0.05$; Figs. 2.31C and 2.31D) and Year 2 ($R^2 = 0.35$ and $R^2 = 0.20$; $p < 0.01$ and $p < 0.05$; Figs. 2.31C and 2.31D).



2.31. Relationships between NO_3-N export and A) sodium export, B) potassium export, C) magnesium export and D) calcium export. ***significant at $p < 0.001$, ** significant at $p < 0.01$ and *significant at $p < 0.05$.

2.5.5 Chemical properties of soil

Table 2.12 Chemical properties of soil during October 2013

Plot	pH	Cond umhos/cm	NO_3-N ppm	P ppm	K ppm	Ca ppm	Mg ppm	S ppm	Na ppm	Organic C %	Total N %	Total N ppm	C:N %
1	6.99	345	3.81	134.92	216.24	1059.69	106.50	23.23	428.31	1.92	0.26	2608.00	7.36
2	6.94	432	2.80	166.60	204.33	1029.02	113.32	28.86	445.44	1.89	0.27	2711.99	6.98
3	6.7	291	4.77	177.01	208.76	1075.91	128.38	31.69	384.47	2.10	0.29	2864.78	7.34
4	6.67	326	3.08	184.22	214.09	1070.95	117.10	29.77	389.61	1.81	0.26	2648.78	6.83
5	6.48	317	0.06	207.22	204.30	1035.88	128.28	41.26	384.94	1.73	0.24	2411.57	7.16
6	6.63	314	1.14	215.62	210.32	927.55	108.40	34.02	379.03	1.62	0.24	2370.13	6.84
7	6.48	254	1.50	208.38	202.44	941.67	99.98	22.19	277.18	1.56	0.24	2440.02	6.41
8	6.98	285	0.65	236.24	184.25	802.07	76.91	32.60	328.50	1.00	0.17	1748.50	5.73
9	6.78	404	0.70	242.83	253.42	1134.69	124.75	43.66	459.10	1.67	0.24	2427.38	6.87
10	6.95	327	1.52	228.47	236.98	1253.71	143.99	38.67	388.17	1.71	0.24	2433.52	7.02
11	6.84	314	0.93	211.27	224.37	1260.06	141.78	40.10	316.35	1.55	0.24	2440.27	6.37
12	6.8	335	0.46	230.74	246.62	1149.37	130.78	29.78	356.38	1.62	0.25	2524.78	6.42
13	6.9	275	0.52	232.46	235.20	1164.85	117.27	26.03	359.73	1.65	0.24	2440.92	6.78
14	6.75	406	0.58	223.48	241.00	996.84	101.53	33.02	541.89	1.60	0.23	2300.01	6.98
15	7.09	493	0.80	213.69	216.62	1404.48	134.59	30.24	504.47	1.27	0.19	1856.67	6.86
16	6.96	260	0.89	245.36	243.24	1090.14	108.30	22.63	386.89	1.18	0.19	1901.88	6.19
17	7.21	334	0.50	212.38	270.70	1123.40	145.91	22.38	308.17	1.11	0.16	1613.91	6.90
18	7.38	319	0.34	267.26	203.14	1056.51	82.11	26.54	424.33	1.12	0.17	1690.30	6.64
19	7.57	317	0.80	233.04	183.15	1036.40	94.14	19.12	394.25	1.07	0.15	1461.53	7.35
20	6.67	317	0.03	280.22	234.11	1118.19	118.85	26.65	293.42	1.20	0.17	1699.84	7.08
21	6.94	356	0.87	272.97	215.68	955.44	82.01	25.96	394.92	1.17	0.20	1953.09	6.01
22	6.61	304	0.56	263.74	290.96	989.33	141.35	19.78	279.15	0.90	0.11	1134.86	7.90
23	7.14	346	0.18	241.03	154.68	893.10	90.24	15.54	296.79	0.71	0.12	1227.49	5.75
24	7.35	389	0.33	229.86	224.44	888.73	82.01	21.19	436.73	1.14	0.18	1813.22	6.31

Table 2.13 Chemical properties of soil during November 2014

Plot	pH	Cond umhos/cm	NO_3-N ppm	P ppm	K ppm	Ca ppm	Mg ppm	S ppm	Na ppm	Organic C %	Total N %	Total N ppm	C:N %
1	6.9	304	7.02	161.04	268.19	1301.61	118.08	30.29	307.50	2.21	0.28	2781.67	7.9
2	7.2	273	2.82	139.00	221.70	1220.08	119.51	22.06	302.06	2.26	0.30	3027.16	7.5
3	6.7	262	5.44	173.21	227.46	1155.12	112.17	21.77	249.93	1.64	0.26	2562.76	6.4
4	7.1	240	3.44	151.66	220.55	1149.36	107.83	16.31	262.91	1.47	0.24	2416.51	6.1
5	7.2	320	3.10	177.14	220.86	1347.32	133.23	25.20	432.91	1.85	0.34	3400.64	5.4
6	7.0	287	2.52	193.43	219.81	1129.48	114.59	23.97	387.11	1.22	0.23	2297.84	5.3
7	6.6	256	1.51	206.31	218.72	1008.50	89.74	17.35	234.42	1.39	0.25	2468.45	5.6
8	7.1	288	0.10	212.53	169.47	807.46	77.95	23.51	304.18	0.81	0.12	1152.00	7.0
9	7.3	281	1.44	185.82	216.30	1168.89	94.92	22.19	433.65	1.48	0.26	2576.56	5.8
10	7.1	265	4.25	177.83	203.75	1386.35	114.59	26.95	317.18	1.80	0.28	2826.09	6.4
11	6.8	305	4.80	194.93	238.07	1410.47	125.04	37.05	251.45	1.86	0.32	3202.70	5.8
12	6.8	267	1.24	195.01	204.44	1205.95	96.07	33.44	297.66	1.65	0.24	2401.93	6.9
13	6.9	288	1.60	239.00	183.98	1191.85	93.94	22.52	267.01	1.40	0.27	2663.27	5.3
14	7.0	317	1.99	203.25	190.85	1106.26	83.01	23.22	388.64	1.39	0.21	2055.85	6.8
15	7.3	264	1.83	192.86	207.59	1166.01	89.45	15.87	390.75	1.51	0.25	2452.03	6.1
16	6.8	291	0.85	236.13	221.38	989.75	89.27	19.91	351.65	1.09	0.17	1706.06	6.4
17	6.9	224	0.50	265.10	198.65	1030.59	85.95	16.93	282.01	0.80	0.18	1782.50	4.5
18	7.2	314	0.68	258.91	171.97	1015.97	80.21	31.65	378.97	0.78	0.19	1860.34	4.2
19	7.3	264	0.67	267.61	188.62	1343.87	91.92	20.44	337.99	1.04	0.18	1779.53	5.8
20	6.9	257	2.19	284.78	187.69	1178.59	96.59	19.52	279.50	1.07	0.19	1942.35	5.5
21	6.9	258	0.18	234.34	191.02	1034.28	88.80	17.72	313.74	1.14	0.21	2096.74	5.4
22	6.6	230	1.47	228.84	217.75	1016.95	90.50	23.19	243.09	1.07	0.22	2209.34	4.9
23	6.7	255	0.19	272.79	196.31	954.06	90.67	15.69	262.16	0.91	0.15	1522.21	6.0
24	7.4	243	1.19	216.12	182.08	935.38	81.07	12.52	330.62	1.03	0.18	1815.96	5.7

2.6 Discussion

Population continues to grow in southern cities of the United States and requires physical development of communities and their landscape from a rural to urban and suburban environment (Colby and Ortman 2015). Urbanization requires vegetation such as trees, turf grass and shrubs not only to render communities aesthetically pleasing, but to prevent soil erosion, improve air quality, control temperatures, increase biofiltration, decrease storm runoff, and store carbon. Therefore, turfgrass continues to dominate the urban and suburban landscape, commonly being used for lawns, recreational parks, neighborhood parks, sports grounds, and golf courses. The condition of homeowner lawns and their management practices can have a substantial impact on the quality and quantity of urban runoff (Milesi et al. 2005). Maintenance of turfgrass generally includes mowing and management of clippings in the simplest form, but with highly managed turfgrass there are the demands for fertilizer, herbicide, fungicide, and pesticide application, and often the installation of in-ground irrigation systems in order to maintain an aesthetically pleasing lawn. Turfgrass, due to its dense nature, should decrease sediment loss, slow the velocity of runoff, and allow more water to infiltrate into the soil; however, due to increasingly limited water supplies and environmental damage associated with lost nutrients, loss of water through runoff and the concomitant transport of nutrients from urban lawns has been receiving increased scrutiny in recent years (Gross et al. 1990).

This study investigated the effect of fertilizer application and deficit irrigation on DOC, DON, and cation annual mean runoff concentrations and runoff exports for a two year period conducted May 2013 through October 2014.

2.6.1 Effect of deficit irrigation on analyte exports

Irrigation is an integral part of turfgrass maintenance and as water resources decline, the efficient use of water in urban landscapes should be the primary focus of water conservation considering 40 to 70% of annual household use of water is landscape irrigation (Ferguson 1987). Typically residential landscapes are overwatered and utilizing less water may impose stress on turfgrass areas resulting in reduced quality. Irrigation at 60% ET_o had a significantly ($p < 0.001$) higher export of sodium compared to 30% ET_o irrigation which may be explained by the higher runoff volumes. The source of irrigation water applied has a significant effect on the load of sodium, potassium, magnesium and calcium. For instance, sodium absorption ratio (SAR) for the municipal tap water used for this study was 32±5 (9.93 meq L^{-1}) compared to 1.5±0 for rain water (Aitkenhead-Peterson in review-a). Similarly, Devitt (2013) used recycled sewage effluent which had a Na^+ concentration (10.86 meq L^{-1}) for turfgrass irrigation in Las Vegas, USA. They reported that 70% of the sodium applied in irrigation water was leached from loamy-sand soil. Aitkenhead-Peterson (in review-b) observed comparable results to those of Devitt et al (2013) where 48±13% of input Na^+ was lost to runoff from the same site this study was conducted. Rengasamy and Olsson (1993) stated that if the

SAR of irrigation water is >3 and the leaching fraction is <50% of the applied water, sodium will accumulate.

In this study, treatments receiving 60% ET_o had similar exports of analytes to 30 and 45% ET_o treatments. This makes sense as the more water added as irrigation, the greater likelihood of runoff and hence export. Morton et al. (1988) reported elevated inorganic N concentrations from overwatered Kentucky bluegrass suggesting that increases in N loading can result from overwatered fertilized lawns which is likely to occur due to the lack of homeowner knowledge regarding soil moisture conditions. Most of the additional N lost from overwatered, fertilized plots has been reported to occur during summer irrigation periods which accounted for 88 and 91% of the annual N lost from the overwatered low and high N treatments but in summer, plants are actively growing and thus should take up larger amounts of N (Morton et al. 1988). Irrigation interval treatments in previous studies found that St. Augustine grass root mass and length was not affected and responded well to once a week irrigation (Peacock and Dudeck 1985). Peacock and Dudeck (1984) also suggested that scheduling an irrigation every 6 days with 23 mm of water will not affect St. Augustine grass turf quality if an adequate mowing height is maintained.

2.6.2 Effect of fertilization on analyte exports

Proper fertilizer management, including appropriate rates, sources, application timing, and proper irrigation after fertilization are important with respect to maintaining aesthetic turfgrass and environmental quality (Gross et al. 1990). In residential areas, lawn fertilization is often cited as a major contributor to non-point source pollution in surface water and groundwater. In this study, fertilizer treatment had a significant effect ($p < 0.05$) on NO_3-N mean exports. Overall, 4X fertilizer treatment had greater NO_3-N exports than 2X fertilizer treatment and 0X treatment, in that order (Appendix E). The fertilizer used in our study constituted of 17.3% urea nitrogen, water soluble nitrogen, and water insoluble nitrogen (methylene urea), soluble potash, sulfur, and iron (32-0-10). St. Augustine turfgrass require up to 150 to 300 kg N ha^{-1} yr^{-1} when appropriately fertilized; however, in our study only 88 or 176 kg N ha^{-1} yr^{-1} was applied (Cisar et al. 1991). Urban lawns with low infiltration, receiving an average of 96 kg N ha^{-1} yr^{-1} had 20 to 150 mg N m^{-2} inorganic N lost after simulated rainfall was applied for 90 min at the rate of about 12 cm hr^{-1} compared to unfertilized areas averaging 12 mg N m^{-2} (Kelling and Peterson 1975). Our results showed a mean export of 24±11 to 327±126 mg N m^{-2} slightly higher than Kelling and Peterson (1975). The result of Kelling and Peterson (1975) also implied that the amount of fertilizer removed with the runoff water was determined by the infiltration properties of the lawn rather than by the amount of fertilizer applied. The research site has a Bt horizon from 18-46 cm with illuvial clay which decreased water infiltration. Irrigation should be sufficient to get the fertilizer in contact with the soil but not enough to induce runoff.

2.6.3 Maintenance of electroneutrality

Information on the exchange properties of soils is essential to understanding the quality of urban runoff. This includes the rate of release of ions, the exchange capacity of the soil, and the degree of ion saturation. The anion-exchange reactions of soils may be described as *"the substitution of an anion by another which is present in solution in greater concentrations or possess a stronger tendency to hold its position on the soil"* (Dean and Rubins 1947). The exchange of anions cause electroneutrality changes until equilibrium is reached through the exchange of cations. For example, when roots take up charged molecules such as nitrate or ammonium they typically release an identically charged molecule to maintain a balanced charge inside the plant cells.

Cations are adsorbed to negatively charged exchange sites on clays and organic matter; when the influx of a particular cation, such as sodium from irrigation water enters the system, it replaces the divalent cations such as calcium and magnesium, releasing them into soil solution and altering the equilibrium of the soil solution. During Year 1, cation and anion exports had significant relationships. This may have been result of the addition of gypsum early January 2013. Gypsum addition promotes displacement of adsorbed Na^{+}. Before treatment commenced in May, 255 mm of rain allowed an exchange of sodium with calcium. During 2014, the relationships among anions and cations were poor. Gypsum was added late March and only 33 mm of rain fell after gypsum addition and prior to the start of deficit irrigation and fertilization treatments. This scenario would unlikely allow equilibrium in terms of calcium replacement of sodium which would have an effect on the relationships observed in year 2 of the study. Qadir et al. (1996) reported a decreasing quantity of Na^{+} over time due to the decreasing efficiency of gypsum and attributed this to the depletion of the Ca^{2+} reservoir which supplied lesser Ca^{2+} to remove and leach the exchangeable Na^{+}. They also saw a significant decrease in pH. The water requirement for reclamation with gypsum will depend on the cation exchange capacity because it acts as a sink for calcium until both gypsum dissolution and exchange reactions achieve equilibrium (Oster and Frenkel 1980). As the salinity of the soil increases, the affinity for sodium increases and the decrease of clay content in soil increases the sodium adsorption/calcium release in soil colloids, forming a sodic soil (Endo et al. 2002).

Relatively few studies have reported or examined annual DOC and DON exports from urban watersheds and even less studies are available from non-point source DOC and DON exports derived from turfgrass and its thatch (Aitkenhead-Peterson et al. 2007;Petrone 2010;Wherley 2015). Previous research has shown that annual DOC and DON exports in urban watershed in Australia ranged from 968 to 2241 kg C km^{-2} yr^{-1} and 42 to 133 kg N km^{-2} yr^{-1} and similar in the upper trinity river below Dallas/Fortworth, Texas, exports were 1533 kg C km^{-2} yr^{-1} and 76 kg N km^{-2} yr^{-1} which may be explained by the exports from our study where DOC ranged from 473 to 6070 mg $m^{-2}yr^{-1}$ and 2329 to 13418 mg $m^{-2}yr^{-1}$ and DON exports of 37 to 400 mg $m^{-2}yr^{-1}$ and 134 to 1018 mg $m^{-2}yr^{-1}$ from fertilized and unfertilized plots (Aitkenhead-Peterson et al. 2009;Petrone 2010).

Relationships between aquatic or soil DOC and DON concentrations and sodium have been reported at the laboratory scale but have not fully accounted for the mechanism that might be responsible for this relationship (Aitkenhead-Peterson et al. 2009;Holgate et al. 2011;Steele and Aitkenhead-Peterson 2012). In order to maintain electroneutrality, an equal negative charge must be released. In addition, sodium will solubilize organic matter by increasing pH and releasing those humic and fulvic molecules (Fettig and Sontheimer 1984). Based on our results we suggest that the variance in the average export of DOC and DON during the first year is significantly explained by the loss of cations and partially explained for the second year. The release of cations were strongly and significantly related to release of DOC and DON. This suggest that sodium was replacing calcium and magnesium on soil exchange sites as it to be expected with application of sodic water in a sandy loam soil.

It has been suggested that DOC release from highly managed turfgrass soils and low mineralization of DOC by soil biota is due to irrigation with sodic water (Aitkenhead-Peterson and Cioce 2013;Cioce and Aitkenhead-Peterson 2015). Aitkenhead-Peterson (in review-b) saw the relationship between cation losses, specifically calcium, was strongly and significantly related to DOC release to runoff from newly installed, fertilized and unfertilized St. Augustine sod irrigated with sodic potable water. Aitkenhead-Peterson (in review-a) theorized that using high sodium tap water used for irrigation would displace divalent cations from soil exchange sites which would require displacement of anions to achieve electroneutrality in soil solution and that these anions would be DON and DOC. Aqueous chemistry dominated by sodium initiates disaggregation of immobile aggregates and mediates colloid transport (McCarthy and Zachara 1989). Monovalent salts do not have the ability to form cation bridges with organic matter, instead they break the bridge linkage of divalent cations and organic matter to the clay mineral surfaces (Greenland 1971). Declining calcium concentrations in soil water can contribute to increasing DOC in runoff by reducing

DOC adsorption in mineral soils caused by cation bridging of lack thereof (Kerr and Eimers 2012). Based on previous research and this study, we suggest that the major mechanism of DOC and DON release from urban landscapes with high sodium irrigation water is likely to be a combination of sodium exchange with cations on soil exchange sites followed by calcium decomplexation and a consequential displacement of adsorbed organic DOC and DON. Alkalinity, generally in the form of the bicarbonate ion was not measured in this study and it is likely due to its weak adsorption to soil exchange sites that this was bulk of anion losses. In an Everett soil series, bicarbonate was the dominant ion under urea fertilization mainly due to the hydrolysis of urea (Johnson and Cole 1980).

Orthophosphate-P had a strong and significant relationship between PO_4-P export and sodium in Year 1. Orthophosphate-P is generally tightly bound to soil exchange sites and its loss is generally assumed to be via sediment losses. At pH > 7.2 phosphorus will react with Ca^{2+} and Mg^{2+}. This site was previously used as a grazing farm for dairy cattle for several years. The high amount of phosphorus in manure may explain why phosphorus concentrations were higher in unfertilized plots due to legacy phosphorus. Dairy manure has a high C: P ratio (87), which may also explain why a higher DOC concentration was found for treatments not receiving fertilizer (McDowell and Sharpley 2003).

Nitrate, generally considered an artifact of excess fertilization is a conservation anion that does not adsorp well to soil exchange sites. Its mobility is regulated mostly by biological processes (Johnson and Cole 1980). However the relationship between NO_3-N export and cations, although significant was poor.

2.7 Conclusion

The use of fertilizer has been purported to lead to losses of N and P, but that may not always be the case. Fertilizer application had no significant effect on the exports of DON, DOC, and orthophosphate even after the collection of rain or forced irrigated events after the application of fertilizer. The effect of irrigation on St. Augustinegras was not significantly different Prior relationships found linking DON and DOC to cations may be due to the maintenance of electroneutrality of soil solution and this study supported that finding. Strong and significant relationships were observed between the anions and cations during Year 1, suggesting the exchange of cations and the release into soil solution allowing them to be transported in runoff. The nature of clay minerals in a soil will determine the negative charge; however, dynamic changes in soil organic matter, aggregate and particle sizes and soil pH, induced by soil management practices, affect the way in which negatively charged sites are chemically bound and the portion of these sites available for sodium and water interactions (Rengasamy and Olsson 1993).

CHAPTER III

CONCLUSION: EFFECTIVENESS OF REGULAR APPLICATIONS OF WETTING AGENT ON SIMULATED ST. AUGUSTINE GRASS LAWNS

3.1 Introduction

Soils in various parts of the world are known to exhibit water repellency or hydrophobic properties that have caused serious land use problems. Research has attributed this to organic materials produced by plant root exudates, fungal species, and decomposing soil organic matter that coat the soil particles with a hydrophobic organic material (Wallis and Horne 1992;Hallett 2007). Water repellency dramatically affects water and solute movement because of non-uniform wetting, retardation or resistance of surface water infiltration and creation of preferential flow paths which pose a risk for ground water contamination (Bauters et al. 2000). The spatial variability of hydrophobicity has been shown to cause non-uniform wetting and preferential flow in many field soils affecting plant growth and resulting in increased irrigation requirements (Ritsema and Dekker 1994;Dekker and Ritsema 1996). Additional consequences of hydrophobicity include the potential for increased runoff, less available water for plant uptake, reduced irrigation efficiency, increased requirement for water and other inputs, and increased potential for non-point source pollution (Moore et al. 2010). The potential for increased runoff of rainfall or irrigation water results in a loss of water which is wasteful. Conversely one key to maximizing plant water availability is maximizing the amount of water infiltrating into or stored in the turfgrass rootzone. Under drought conditions it is especially important to optimize the use of irrigation for turfgrass quality and while conserving water (Kostka et al. 2011).

3.1.1 Soil water repellency

In hydrology, the degree of soil water repellency has become increasingly important in several countries (Letey et al. 2000). Water repellency is evident in coarse textured sandy soils that are often found in coastal regions of Southern USA because sand grains become coated with certain hydrophobic organic compounds (Miller and Wilkinson 1977;Cisar et al. 2000). Golf greens are constructed from sandy soils that are very prone to the development of water repellency and once developed are difficult to re-wet (Cisar et al. 2000).

The water drop penetration time (WDPT) is a simple and commonly used method to quantify the degree of soil water repellency. The WDPT method involves placing a drop of water on the soil and measuring the time for it to penetrate (Letey et al. 2000;Kostka et al. 2011). If a drop of water does not infiltrate the soil spontaneously, the soil-water contact angle is greater than 90º and thus the soil is considered hydrophobic (Letey et al. 2000). The WDPT was researched on a turfgrass grown on sand based greens with a history of soil water repellency of three commercial products, AquaGro, Primer, and Aqueduct which had lower WDPT than the control with the exception of AquaGro in 0-2 cm (Cisar et al. 2000). Pelishek et al. (1962) concluded that the effect of a wetting agent on infiltration is dependent upon the liquid-solid contact angle and can have either no effect or adverse effects on soils which are not particularly hydrophobic.

3.1.2 Wetting agents

Wetting agents or soil surfactants have been used commercially to improve soil conditions and increase water infiltration in golf courses since the introduction of the original soil surfactant, AquaGro, during the mid-1950s (Rice and Horgan 2011). Wetting agents have provided the most immediate solution to combating soil water repellency when compared to other physical, chemical, and biological approaches, particularly on large commercial areas (Dekker et al. 2005;Hallett 2007;Cisar 2012). Wetting agents have also been used as a part of regular maintenance to relieve localized dry spots, to manage water, to improve drainage, and to improve pesticide movement into the soil (Karnok et al. 2004).

The nonionic surfactant composition of wetting agents allow water to wet the soil particle by allocating the polar portion of the wetting agent to bond to the water while the nonpolar portion bonds to the nonpolar organic coating (Karnok et al. 2004). These chemicals possess a water soluble hydrophillic group attached to a long, oil soluble lipophillic hydrocarbon chain and cause physical changes at the surface of liquids (Karnok et al. 2004). The wetting agents are also able to disrupt the cohesive forces of water molecules responsible for expressing surface tension, thus decreasing the surface tension of the liquid, increasing infiltration rate, and allowing for better penetration of water into a hydrophobic soil (Schiavon et al. 2014b). Common components of wetting agents include alkyl polyglycoside and ethylene oxide/propylene oxide block copolymer (Chaichi et al. 2015). In potato hills, surfactants were comprised of 89.5% alkylphenol ethoxylate, sodium salts of soya fatty acids, isopropyl alcohol, and 10.5% constituents ineffective as spray adjuvant (Arriaga et al. 2009). These surfactants do not form insoluble salts with calcium, magnesium or ferric ions and have relatively low toxicity to plants (Karnok et al. 2004).

3.1.3 Water runoff

Soils in many countries exhibit soil water repellency or hydrophobicity which reduces water infiltration and water movement within the soil, causing surface pooling or runoff (Wallis and Horne 1992;Hallett 2007). Under hydrophobic conditions, when rain or irrigation water falls or flows over a turfgrass, it will not infiltrate the soil uniformly, instead it will move downwards through channels and pathways of least resistance, (preferential flow paths) often by passing large patches of dry soil which are only wetted during prolonged periods of heavy rainfall (Vernon 1945;Kostka et al. 2011).

Research has shown that wetting agents can increase infiltration rate, increase time to runoff, and reduce total runoff (Morgan et al. 1966;Mitra et al. 2006). Water repellent sands in a sloped fairway at a golf course in the Netherlands had lower runoff and increased soil moisture after the application of a soil surfactant (Oostindie et al. 2005). A loamy sand soil with established hybrid bermudagrass turf maintained under fairway management conditions and 8% slope was treated with a wetting agent and had an infiltration rate 1.4 times greater compared to an untreated soil (Mitra et al. 2006). This same treated soil had an increased time to runoff (from 20 minutes to more than 40 minutes) and a reduction in total runoff by 30% (Mitra et al. 2006). Osborn et al. (1964) established six plots with an average slope of 65% with a sandy loam texture in a forested area that was burned over by a wildfire in California. The soil surface had an ash layer of about 1.27 cm (0.5 in) deep underlain by a 5.08 to 7.62 cm (2 to 3 in) layer of partially ashed and decomposed litter, which was very hydrophobic (Osborn et al. 1964). Three of the plots were treated with a wetting agent and had a 32% decrease in runoff compared to untreated plots (Osborn et al. 1964;Osborn et al. 1967).

Infiltration of water into the soil increases with wetting agents. Two commercial surfactants, Aqueduct and Primer were applied weekly at golf courses in New Jersey and Arkansas at a rate of 205 mL 100 m^{-2} (Kostka et al. 2011). The same wetting agents were applied monthly on golf courses in Australia at a rate of 125 mL 100 m^{-2} and 190 mL 100 m^{-2} and in the Netherlands at a rate of 190 mL 100 m^{-2} (Kostka et al. 2011). Soils in New Jersey, Arkansas, and Australia projects were putting greens built to USGA specifications and the Netherlands project had a fine sand with less than 3% clay (Kostka et al. 2011). Their treatments increased rootzone volumetric water content, reduced water repellency, shifted critical moisture content, and improved infiltration rate of applied irrigation water.

There is multiple evidence that wetting agents are effective in commercial properties in terms of increasing water infiltration into the soil profile. More recently there has been an interest in expanding the use of wetting agents to home lawns where they may have beneficial effects such as increasing water infiltration into the soil, improving distribution and availability of water in soils, and reducing the volume of runoff as well as the export of nutrients lost in runoff (Park et al. 2005;Mitra et al. 2006). However, many native soils differ texturally from those of constructed turf systems, which are often sand based and hydrophobicity may be more of an issue with sands (Ma'Shum et al. 1989).

3.1.4 Effect of wetting agents on inorganic nitrogen loss

Little information is published concerning the effectiveness of these wetting agents in the reduction of inorganic nitrogen in runoff but previous research on wetting agents or surfactants, showed increased inorganic nitrogen retention and reduced inorganic nitrogen leaching after a wetting agent had been applied to a potato hill (Kelling et al. 2002;Cooley 2005;Arriaga et al. 2009). Application of a wetting agent also resulted in greater amounts of nitrogen taken up by the plants (Arriaga et al. 2009).

3.1.5 Objectives and hypothesis

The objectives of this study were

Quantify the effectiveness of regular applications of wetting agent at reducing exports inorganic N and P from St. Augustine grass lawns

The hypotheses for this research were

H_0: There will be no significant difference in concentrations and exports of NO_3-N, NH_4-N, and, PO_4-P with the application of a wetting agent

$H_{1:}$ NO_3-N, NH_4-N, and, PO_4-P concentrations and exports will be significantly lower in treatments receiving a wetting agent as less runoff will occur in those treatments due to more efficient use of nutrients in solution by turfgrass roots.

3.2 Materials and methods

3.2.1 Study site

Research was conducted at the Texas A&M University/Scotts Miracle Gro Runoff Research Facility at the Texas A&M Urban Ecology Field Laboratory, in College Station, TX (N 30.618178, W -96.366250). A 1,000 m^2 facility containing 24 individual 33.6 m^2 field plots with an average slope of 0.037 m m^{-1} was used in this study. Twenty of the plots were used to measure total runoff volumes at a 2 min temporal resolution and simultaneously sample runoff water at a 38 L (10 gallon) pacing. The previous land use at this site was cattle grazing for a dairy farm and the probability for soils saturated with legacy phosphorus is high (Chapter II).
The climate in this region is humid subtropical with a mean annual temperature of 20° C and an average precipitation for 2014 of 662.9 mm (Chapter II).

St. Augustine (*Senotaphrum secundatum* (Walt.) Kuntze) turfgrass was installed as a sod in August and September 2012 (Wherley et al. 2014). The turfgrass was mowed weekly using a standard push rotary mower with mulching blades set to a 6.3 cm height of cut and the clippings were left on the surface. Disease and weed management were performed based on historical knowledge of the area. The turfgrass was maintained to accommodate Texas homeowner irrigation regulations for many communities, which allows two irrigations days per week. Irrigation in this study was applied on Tuesdays and Fridays.

There are two soil series at the study site. The Boonville series is a fine, smectitic, thermic Chromic Vertic Albaqualf generally occurring on 0-3% slopes and is present on Blocks 1 and 2 (Chapter II). The Zack series is a fine, smectitic, thermic Udertic Paleustalfs generally occurring on a 1-5% slopes and is present on Blocks 2 and 3 (Chapter II). The depth from the top soil to the clay at the runoff plots ranged from 0.305 to 0.405 m in Block 1, from 0.26 to 0.515 m in Block 2, and from 0.25 to 0.40 m in Block 3 (Wherley et al. 2014).

3.2.2 Experimental design

The research design was unbalanced because there were limited plots available for use. Five treatments were established; having four replicates arranged randomly within the twenty plots (Table 3.1). For the current project, we implemented a 2 x 2 factorial design with two wetting agent and 2 fertilizer treatments each receiving irrigation at 30% ET_o. An additional treatment of irrigation at 60% ET_o with zero wetting agent and fertilizer was also included (Table 3.1).

The first application of wetting agent was made on 5 June 2015 and subsequent applications were made monthly thereafter (Table 3.3). Wetting agent was applied at a rate of 0.955 mL m^{-2} (3 liquid oz. per 1,000 square feet) and 6 applications were given over the growing season (Table 3.1).

Southern Turf Builder (32-0-10, N-P_2O_5-K_2O; Scotts Miracle-Gro, Marysville, OH) was applied at a rate of 1.49 kg m^2 (1lb N per 1,000 ft^2) which was divided into two applications. The first application was on June 5, 2015 and the second in July 14, 2015 (Table 3.2).

Plots were watered immediately after fertilizer application with 2.5 mm of irrigation water and applied on the day before a scheduled irrigation event. Temperature data (average ºC) was obtained from Weather Underground archives for station KCLL. Rainfall volumes (mm) were measured on site were measured using a tipping rain gauge (Isco 647, Teledyne Isco, Lincoln, NE) at a two minute temporal resolution. Each plot was equipped with a 1.2 m H flume, an Isco model 4230 Bubbler Flow Meter, and an Isco model 6712 Portable Sampler that collected the rain or irrigation induced runoff (Teledyne Isco, Lincoln, NE 68504). Forced runoff was initiated by irrigating at an average precipitation rate of 37.6 mm hr^{-1} for a 45 min period delivering an average of 28.2 mm. Each plot had its own totalizing water meter to record the volume of irrigation water applied. Water volumes added to each plot were recorded and used in analysis.

The irrigation run time was adjusted to apply amounts equal to the cumulative evapotranspiration deficit which was calculated as:

$$\mathrm{ET_{Def}} = \sum \llbracket \mathrm{K_s} * \left[0.6 * \mathrm{ET_o} - R_{eff}\right\rrbracket$$

Where K_s is a stress coefficient, 0.6 is the warm-season turfgrass crop coefficient, ET_o is the daily reference ET calculated using the FAO-56 Penman Monteith method and R_{eff} is the daily effective rainfall (Allen et al. 1998).

Table 3.1. Plot treatments for wetting agent application

Treatment #	ETo (%)	Cumulative Rainfall (mm)	Cumulative Irrigation (mm)	Irrigation water each plot (L)	Wetting agent (mL m^{-2})	Fertilizer (kg N m^{-2})
1	60	251.6	484.33	16,273	0	0
2	30	251.6	242.16	8,136	0.955 (6)*	0.75 (2)*
3	30	251.6	242.16	8,136	0	0.75 (2)*
4	30	251.6	242.16	8,136	0.955 (6)*	0
5	30	251.6	242.16	8,136	0	0

*Number of Applications

Table 3.2. Fertilizer and wetting agent application dates

Year	Fertilizer	Wetting Agent
2015	6/5/2015	6/5/2015
		7/2/2015
		7/28/2015
	7/14/2015	8/27/2015
		9/22/2015
		10/21/2015

3.2.3 Sample collection and processing

Nine runoff events were captured starting on April 27, 2015, of these six events were captured after treatments started in June 5, 2015 (3 rain events and 3 forced irrigation events) (Fig. 3.1). For each runoff event, five runoff samples for each rain or forced irrigation for each plot were collected (evenly spread throughout the hydrograph) for analysis. The pH (Excel XL20, Fisher Scientific, Pittsburgh, PA, USA) and electrical conductivity (Excel XL20, Fisher Scientific, Pittsburgh, PA, USA) were quantified on unfiltered samples. Samples were filtered through a 0.7 µm filter paper (Grade F, Lab Depot Inc., Dawsonville, GA, USA) prior to chemical analysis.

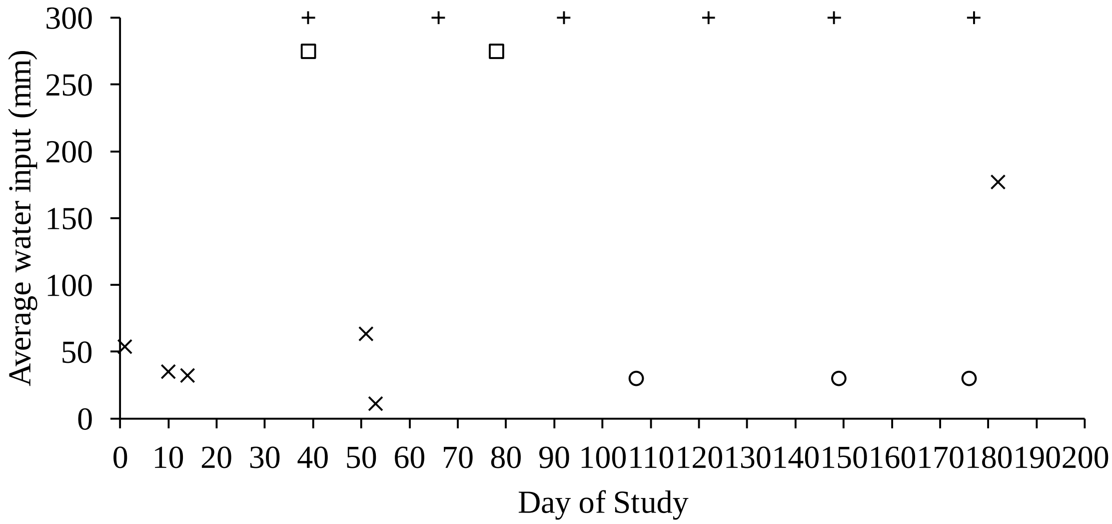


Fig. 3.1 Runoff events before and after the first wetting agent application. X are rain events that induced runoff for capture, O is a forced irrigation, □ indicates fertilizer application, + indicates wetting agent application.

Table 3.3 Rainfall and irrigation volumes

Date	Day of study	Average water input (mm)
4/27/2015	1	53.8
5/6/2015	10	35.1
5/11/2015	14	32.4
6/17/2015	51	63.2
6/19/2015	53	11.2
8/12/2015	107	30.0
9/23/2015	149	30.0
10/20/2015	176	30.0
10/26/2015	182	177.2

3.2.4 Chemical analysis

All nitrate-N was analyzed within 18 h of sample collection. All samples were analyzed within 2-3 days of collection or frozen for future analysis. Nitrate-N was analyzed using Cd-Cu reduction and N-(1-naphythyl)-ethylenediamene dihydrochloride to yield a colored azo dye that is colorimetrically detected at 550 nm, following the EPA method 353.2. NH_4-N was analyzed using phenate hypochlorite with a Na-nitroferricyandide (pH 12.8-13) to produce a blue-green color detected at 660 nm. Orthophosphate-P was analyzed using the ammonium molybdate EPA method 365.1. All colorimetric methods were performed with a Westco Scientific Smartchem Discrete Analyzer (Westco Scientific Instruments Inc., Brookfield, CT, USA).

Sample replicates, blanks, NIST (National Institute of Standards and Technology) traceable and check standards were run every 10th sample to monitor instrument precision and co-efficient of variance among replicate samples.

Samples collected on October 26, 2015 were not analyzed for nitrate-N until November 8, 2015 due to reagent problems with the cadmium column on the instrument, therefore the samples were frozen immediately after collection.

3.2.5 Measurement of % green cover

A camera was used to capture 2 images (1 upslope and 1 downslope) for each plot. A light box with a fluorescent bulb was used to create a standard light each day. The images were analyzed with SigmaScan to measure the percentage of green pixels (Karcher and Richardson 2003).

3.2.6 Calculation of imports and exports

Import of water to each plot was calculated by converting mm of rain or irrigation on the plots to liters for each plot. Total runoff was calculated as cumulative liters for each plot.

3.2.7 Statistical analysis

Mean concentrations of NO_3-N, NH_4-N, and PO_4-P were calculated for each plot for each runoff event. Total runoff volume for each plot for each runoff event were recorded. Mean concentrations were multiplied by runoff volume for each plot and runoff event to assess load leaving plot and divided by plot area to gain export (mg m^{-2} event $^{-1}$) for each plot for each runoff event.

For each irrigation x wetting agent treatment (n =4 per treatment) the mean concentrations for each treatment were averaged and the standard deviation calculated. Univariate analysis of variance with water source (rain vs forced runoff), $\%ET_o$, fertilizer, and wetting agent as fixed factors to asses any significant effect of irrigation, fertilizer, or wetting agent or interactions of the main factors on a) concentrations and b) exports of inorganic N and P. A one-way analysis of variance (ANOVA) was performed on NO_3-N, NH_4-N, and PO_4-P ($\alpha = 0.05$) to determine significant difference among treatment combinations. Statistical analysis only included those runoff events after treatments commenced (N = 6). Time series charts for the exports of NO_3-N, NH_4-N, PO_4-P, percent water retention, and percent water runoff were created which included the baseline concentrations before treatments went into effect (N = 9). All statistical analysis was completed using SPSS v.22.0 (IBM Corp., Armonk, NY, USA). For ease of comprehension the results will be described in the text as follows:

60% ET_o + 0 fertilizer + 0 wetting agent	60-0-0
30% ET_o + 0 fertilizer + 0 wetting agent	30-0-0
30% ET_o + 0 fertilizer + wetting agent	30-0-1
30% ET_o + fertilizer + 0 wetting agent	30-1-0
30% ET_o + fertilizer + wetting agent	30-1-1

3.3 Results

3.3.1 pH and electrical conductivity

For the five months after the first application of treatments the pH ranged from 5.6±3.7 in the rain induced 30-0-0 (ET_o-Fertilizer-Wetting Agent) treatment to 8.7±0.2 in the forced irrigation 30-0-0 and 30-0-1 treatments (Fig. 3.2). Univariate analysis of variance determined that there was a significant effect of runoff induced water source ($p < 0.005$) on pH but no significant effect of fertilizer, wetting agent, or irrigation rate (60% ET_o vs 30% ET_o). Here pH was significantly higher in irrigation induced runoff when compared to precipitation induced runoff but there was no significant difference among treatments within each source water group.

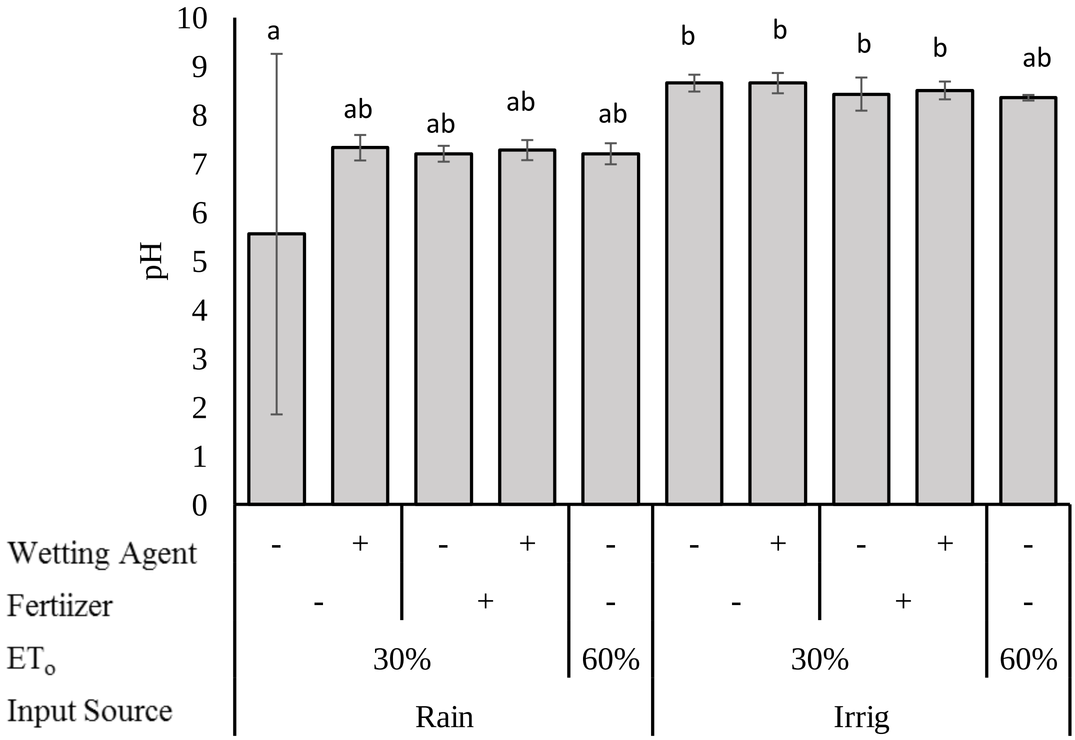


Fig. 3.2. Mean pH in runoff water. Error bars represent the standard deviation. - represents no addition of amendment and + represents addition of amendment. Different lower case letters indicate significant differences among treatments.

Electrical conductivity of runoff solution ranged from 209.7±155 µS cm^{-1} in the rain induced 30-0-0 treatment to 1410.4±157 in the forced irrigation 30-0-0 treatment (Fig. 3.3). Univariate analysis of variance determined that there was a significant effect of runoff induced water source ($p < 0.001$) on electrical conductivity but no significant effect of fertilizer, wetting agent, or irrigation rate (Table 3.4-3.5). Here, significantly higher EC was observed for all treatments where runoff was induced by forced irrigation compared to all treatments where runoff was induced by precipitation.

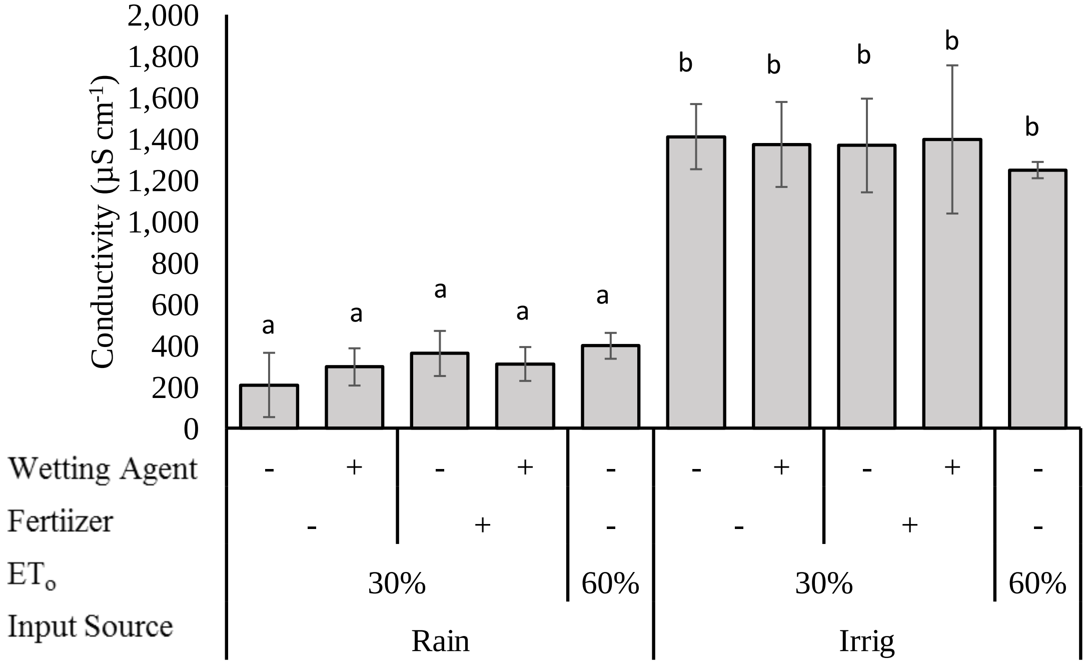


Fig. 3.3. Mean conductivity in runoff water. Error bars represent the standard deviation. - represents no addition of amendment and + represents addition of amendment. Different lower case letters indicate significant differences among treatments.

Table 3.4 ANOVA table of main effects on pH and electrical conductivity. Bold values indicate significant effect at alpha < 0.05.

Main Effects		
	pH	EC
Wetting agent	0.261	0.910
Fert	0.471	0.552
ET_o	0.265	0.875
H_20 Source	**0.003**	< **0.001**

Table 3.5 ANOVA table of interaction effects on pH and electrical conductivity

Interaction Effects		
	pH	EC
H_20 Source * ET_o	0.111	0.053
H_20 Source * Fert	0.249	0.458
H_20 Source * WA	0.299	0.857
Fert * WA	0.341	0.774
H_20 Source * Fert * WA	0.299	0.411

3.3.2 Water runoff and water retention

Water runoff ranged from 8±12% of the total water input volume on the plots receiving 30-0-0 and 30-0-1 treatments to 28±23% in the 60-0-0 treatment. Univariate analysis of variance determined that there was a significant effect of irrigation rate ($p < 0.001$) and fertilizer application ($p < 0.001$) on the volume of runoff but no effect of wetting agent.

Water retention on the plots ranged from 72±16% of the total water load on the plot receiving 60-0-0 treatment to 92±12% in the treatments receiving 30-0-0 and 30-0-1 treatment. Univariate analysis of variance determined that there was a significant effect of irrigation rate ($p < 0.001$) and fertilizer application ($p < 0.001$) on water retention but no effect of wetting agent.

3.3.3 Inorganic nitrogen

NH_4-N concentrations ranged from 0.2±0.0 mg N L^{-1} in the forced irrigation 60-0-0 treatment to 2.2±3.3 mg N L^{-1} in the rain induced 30-1-0 treatment (Fig. 3.4). Univariate analysis of variance determined that there was a significant effect of the source of water input generating runoff ($p = 0.058$). There were no significant effects of fertilizer ($p = 0.40$), wetting agent ($p = 0.77$), or irrigation rate ($p = 0.60$) on NH_4-N concentrations (Fig. 3.4).

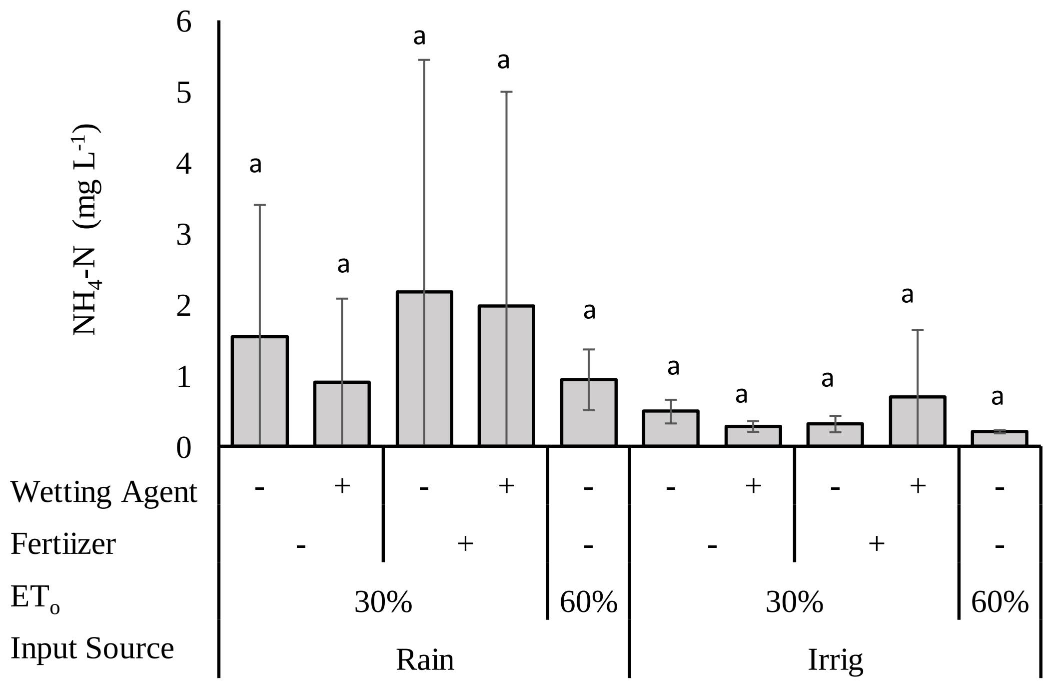


Fig. 3.4. Mean concentrations of NH_4-N in runoff water. Error bars represent the standard deviation. - represents no addition of amendment and + represents addition of amendment. Lower case letters indicate no significant differences among treatments.

NO_3-N concentrations ranged from 0.30±0.14 mg N L^{-1} in the rain induced 30-0-0 treatment to 2.43±1.6 mg N L^{-1} in the forced irrigation runoff 30-0-0 treatment (Fig. 3.5). Univariate analysis of variance determined that there was a significant effect of runoff induced water source ($p < 0.001$). There was no significant effect of wetting agent ($p = 0.29$), fertilizer ($p = 0.86$), or irrigation rate ($p = 0.29$) on NO_3-N concentrations (Fig. 3.5).

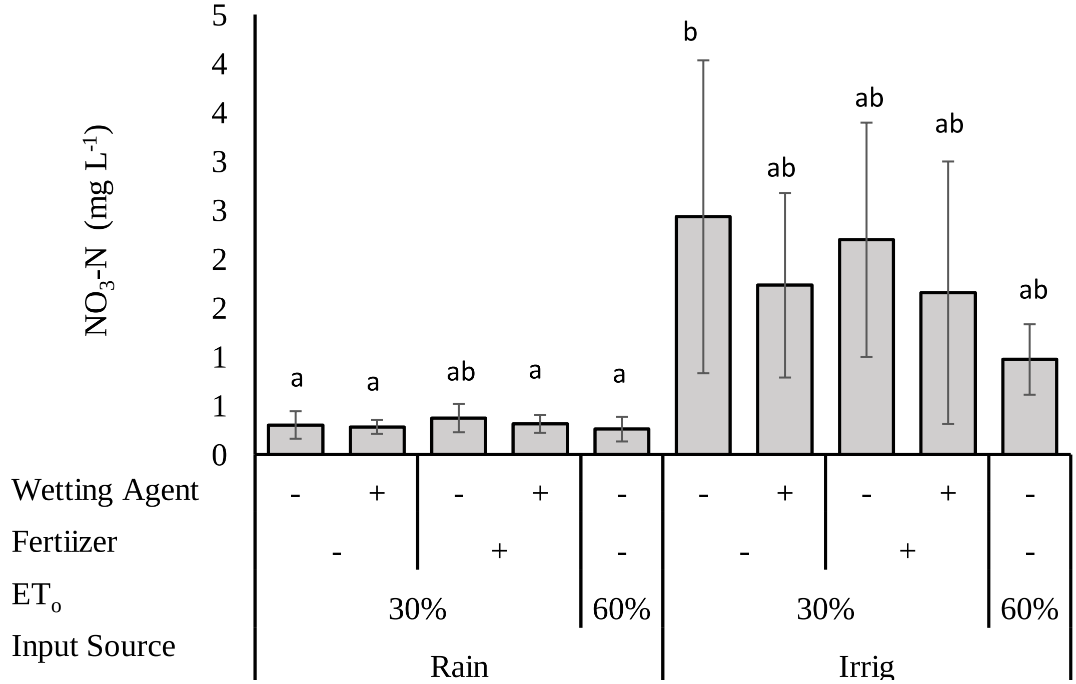


Fig. 3.5. Mean concentrations of NO_3-N in runoff water. Error bars represent the standard deviation. - represents no addition of amendment and + represents addition of amendment. Different lower case letters indicate significant differences among treatments.

3.3.4 Orthophosphate

PO_4-P concentrations ranged from 4.1±1.7 mg L^{-1} in the irrigation induced runoff for the 30-0-1 treatment to 7.2±1.4 mg L^{-1} in the rainfall induced for the 30-0-1 treatment (Fig. 3.6). Univariate of analysis of variance determined that there was no significant effect of irrigation source ($p = 0.16$), wetting agent ($p = 0.28$), fertilizer ($p = 0.88$), or irrigation rate ($p = 0.89$) on PO_4-P concentrations (Table 3.6-3.7).

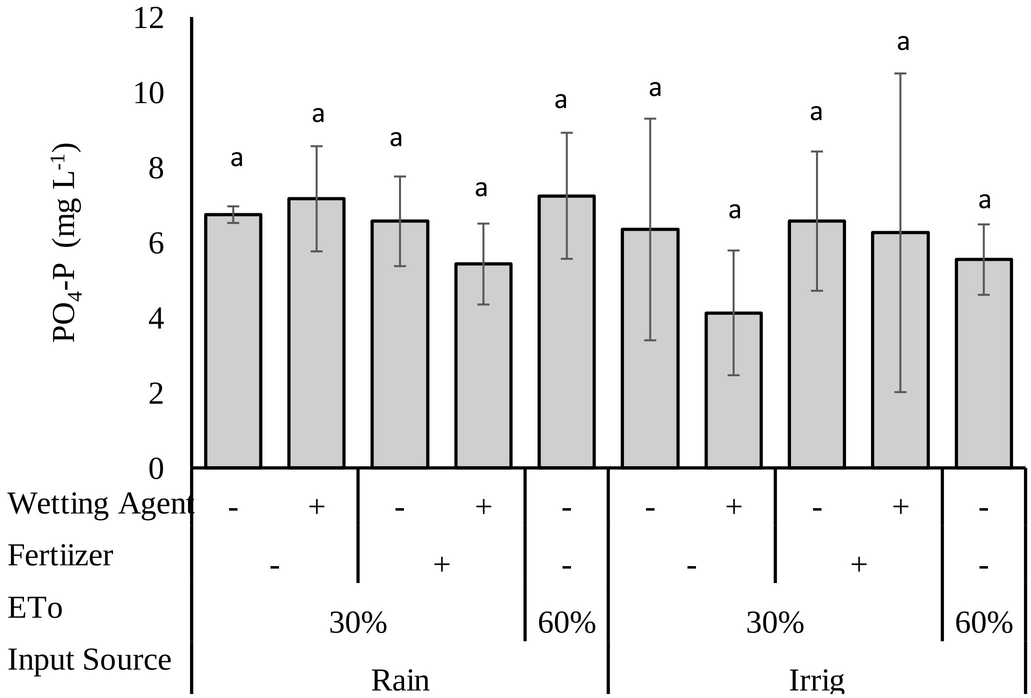


Fig. 3.6. Mean concentrations of PO_4-P in runoff water. Error bars represent the standard deviation. - represents no addition of amendment and + represents addition of amendment. Lower case letters indicate no significant differences among treatments.

Table 3.6 ANOVA of main effects on average concentrations of inorganic N and P. Bold values indicate significant effects at alpha < 0.05.

Main Effects			
	NO_3-N	NH_4-N	PO_4-P
Wetting agent	0.287	0.774	0.285
Fert	0.863	0.404	0.884
ET_o	0.098	0.598	0.890
H_20 Source	**<0.001**	**0.058**	**< 0.001**

Table 3.7 ANOVA of interaction effects on average concentrations on inorganic N and P

Interaction Effects			
	NO_3-N	NH_4-N	PO_4-P
H_20 Source * Et_o	0.118	0.850	0.548
H_20 Source * Fert	0.737	0.527	0.162
H_20 Source * WA	0.348	0.667	0.547
Fert * WA	0.924	0.659	0.907
H_20 Source* Fert * WA	0.872	0.949	0.254

3.4 Time series of analytes

Time series become important when determining whether an application of wetting agent, fertilizer, or other amendment is lost to runoff immediately after its addition during a rain or forced runoff event. Typically a time series of concentrations is examined but the importance of export (mg m^{-2}) is key because it also takes into account the volume of runoff (L) as well as the concentration in that runoff (mg L^{-1-}) and normalized the load to a mg m^{-2} value (Figs. 3.7-3.11).

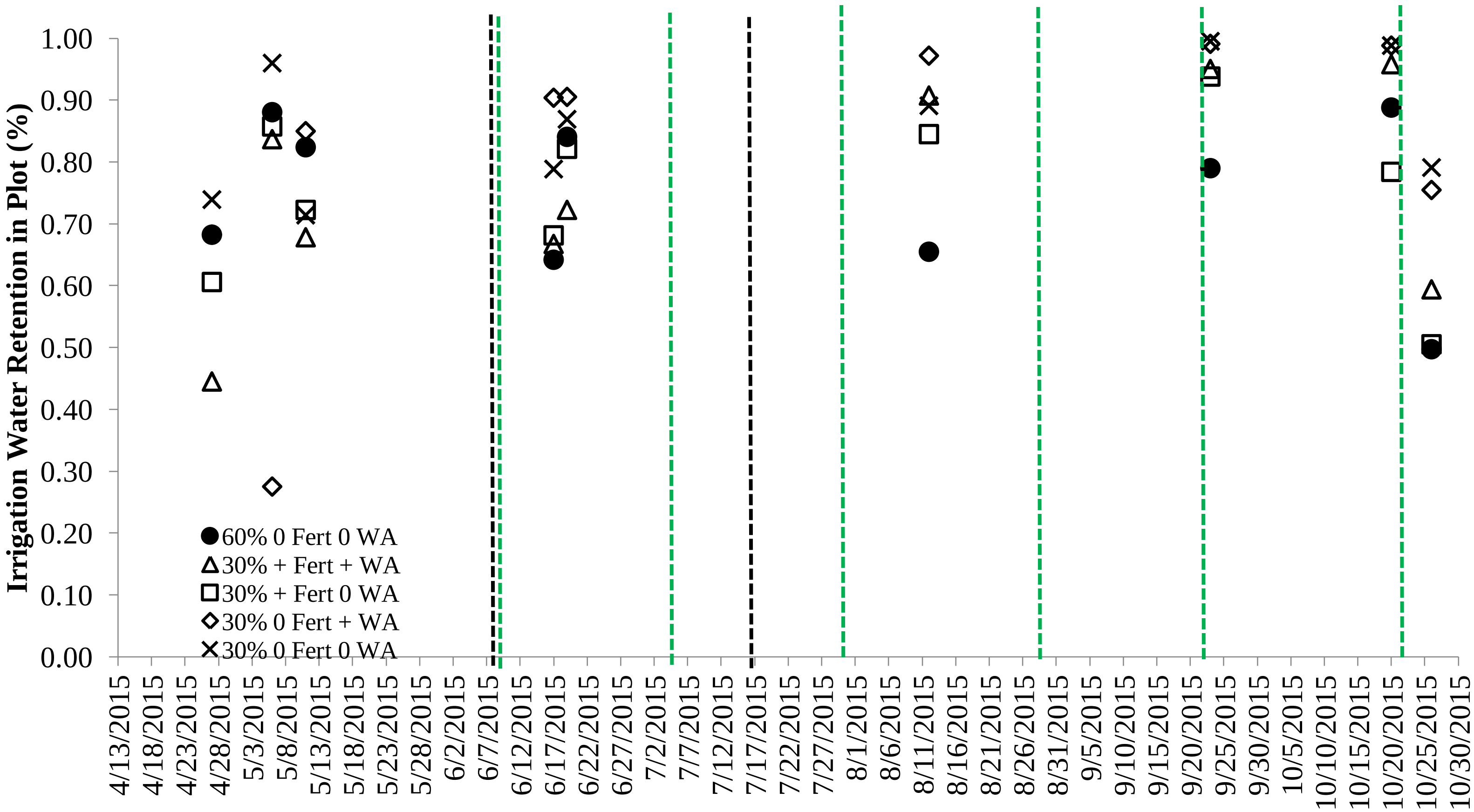


Fig. 3.7. Time series of irrigation water retention. Green hatched lines indicate wetting agent addition and black hatched lines represent fertilizer addition.

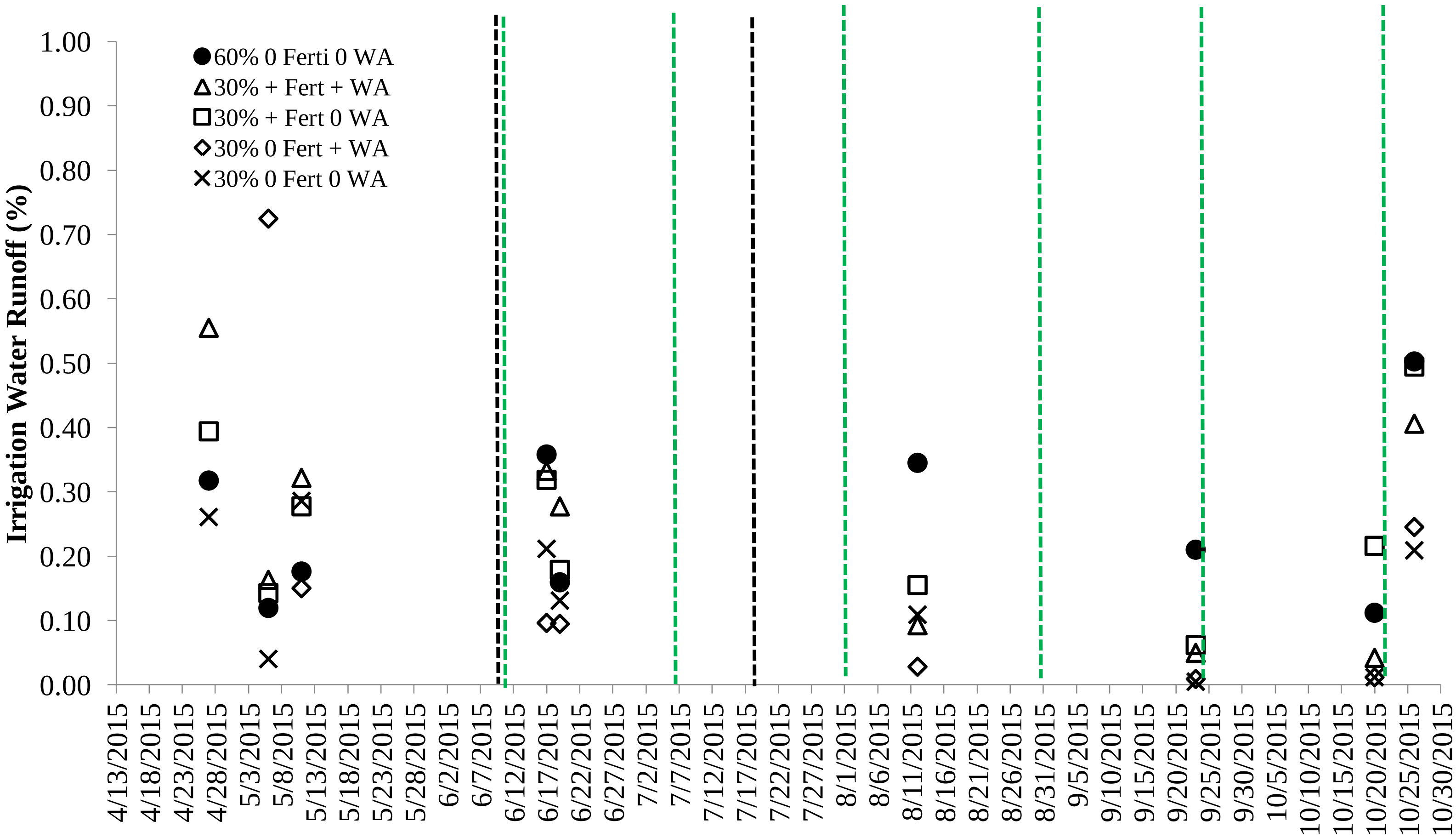


Fig. 3.8. Time series of irrigation water runoff. Green hatched lines indicate wetting agent addition and black hatched lines represent fertilizer addition.

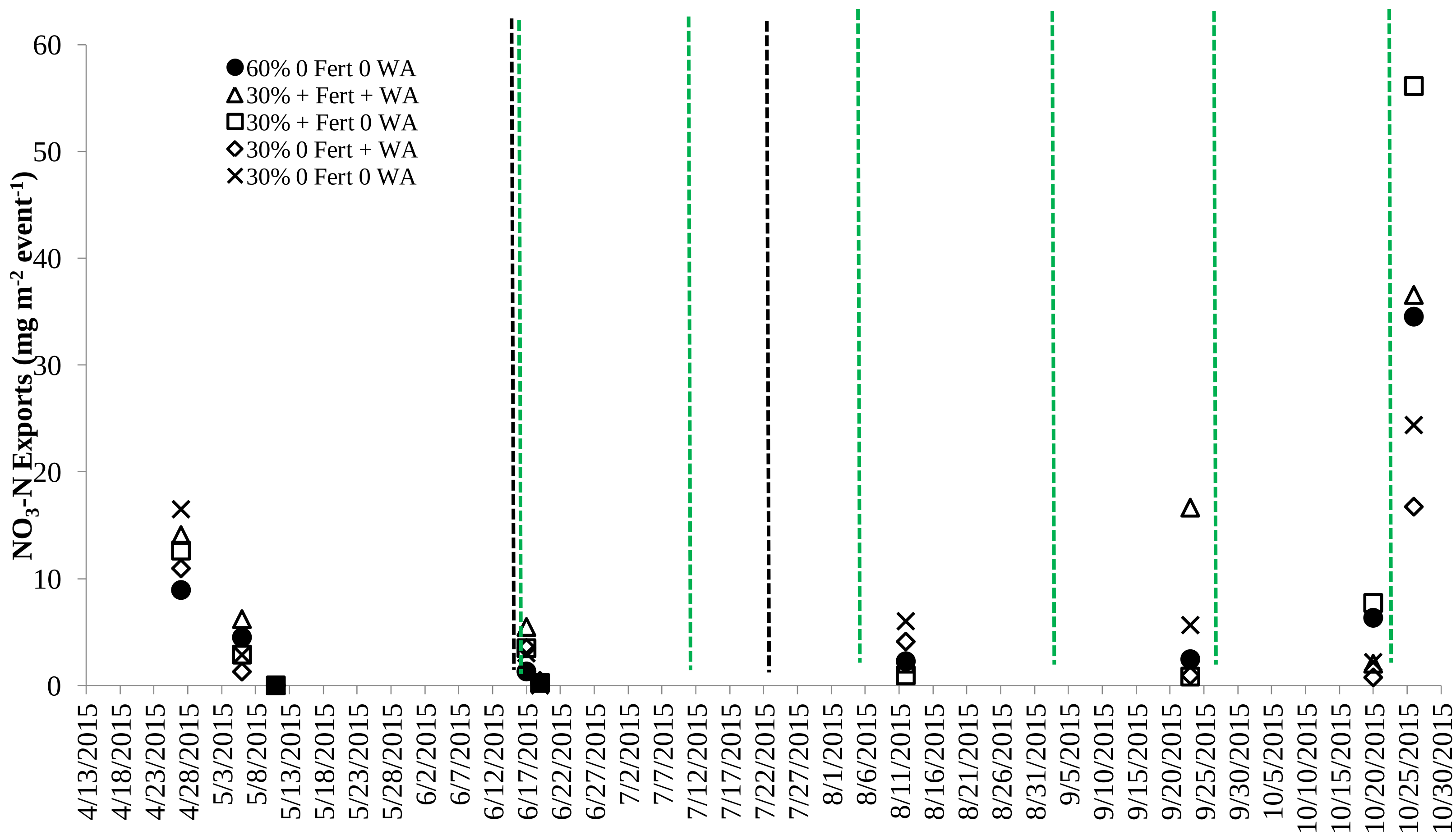


Fig. 3.9. Time series of mean NO_3-N exports in runoff water. Green hatched lines indicate wetting agent addition and black hatched lines represent fertilizer addition.

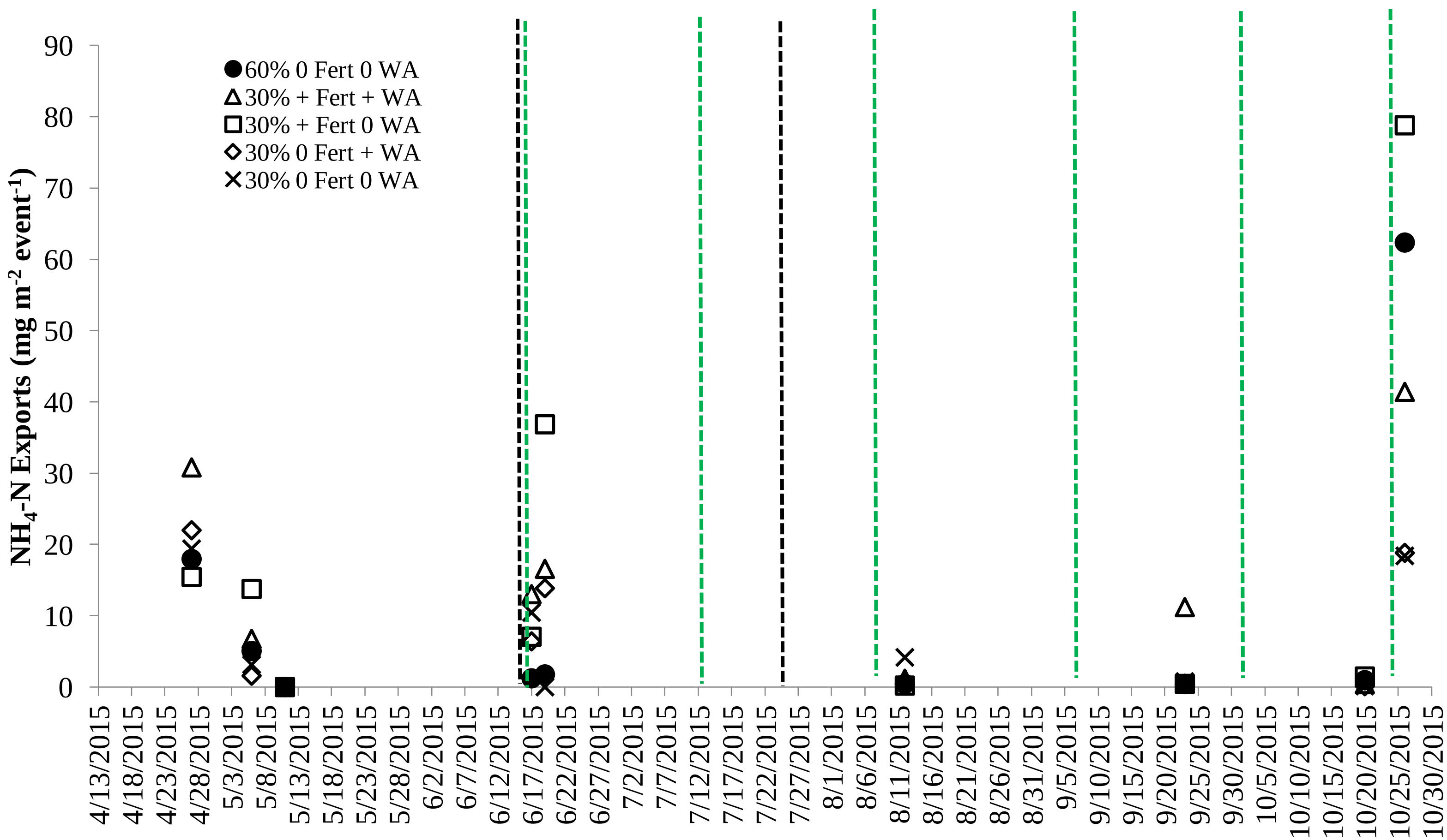


Fig. 3.10. Time series of mean NH_4-N exports in runoff water. Green hatched lines indicate wetting agent addition and black hatched lines represent fertilizer addition.

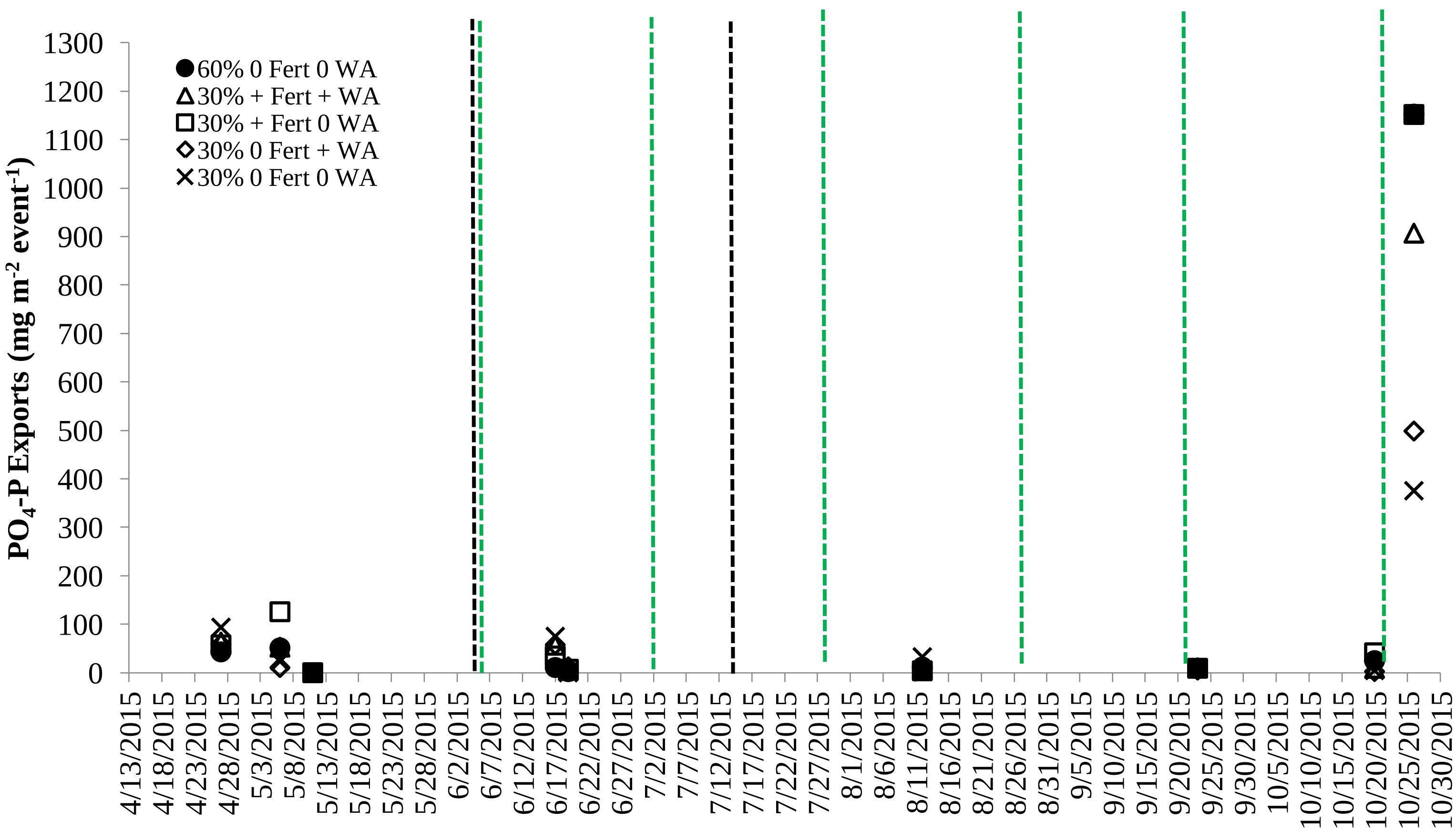


Fig. 3.11. Time series of mean PO_4-P exports in runoff water. Green hatched lines indicate wetting agent addition and black hatched lines represent fertilizer addition.

3.5 Export of analytes

3.5.1 Inorganic nitrogen

NH_4-N exports ranged from 1.0±0.3 mg N m^{-2} in the forced irrigation 30-0-1 treatment to 101.7±76.4 mg N m^{-2} in the rain induced 30-1-0 treatment (Fig. 3.12). Univariate of analysis of variance determined that there was a significant effect of the source of water input generating runoff ($p < 0.001$), fertilizer application ($p = 0.007$), and interaction between water input and fertilizer application ($p = 0.017$). There were no significant effects of wetting agent ($p = 0.51$) or irrigation rate ($p = 0.25$) on NH_4-N exports.

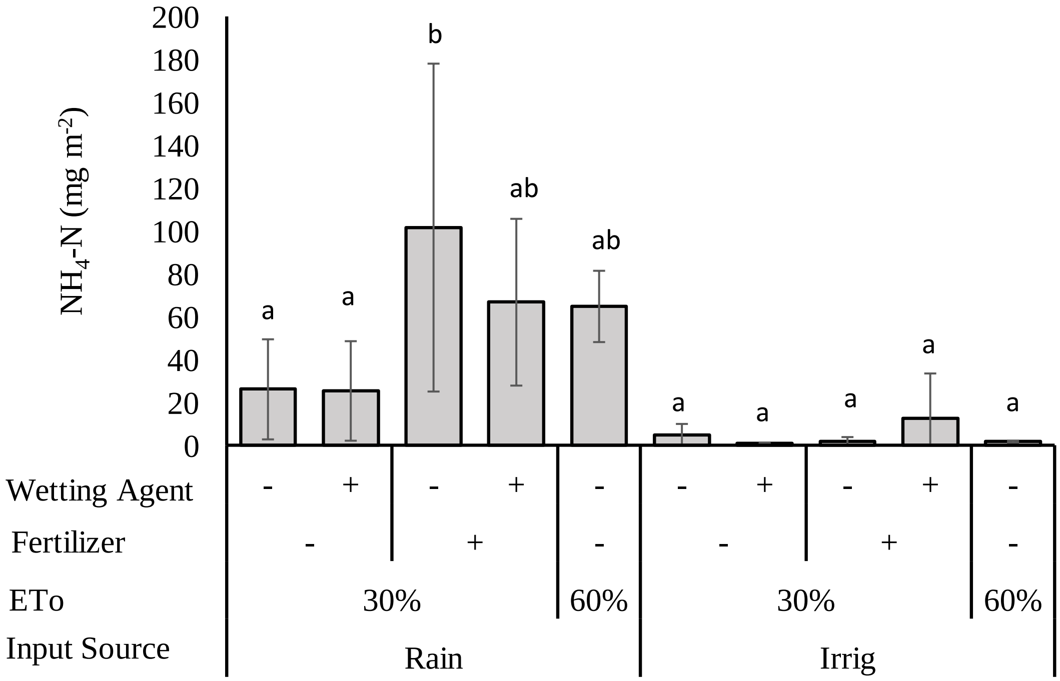


Fig. 3.12. Mean NH_4-N exports in runoff water. Error bars represent the standard deviation. - represents no addition of amendment and + represents addition of amendment. Different lower case letters indicate significant differences among treatments.

NO_3-N exports ranged from 5.6±5.6 mg N m^{-2} in the forced irrigation runoff 30-0-1 treatment to 58.3±49.5 mg N m^{-2} in the rain induced runoff for the 30-1-0 treatment (Fig. 3.13). Univariate analysis of variance determined that there was a significant effect of runoff induced water source ($p < 0.004$) and a slight effect, though not significant, of fertilizer addition ($p = 0.068$). There was no significant effect of wetting agent ($p = 0.57$) or irrigation rate ($p = 0.75$).

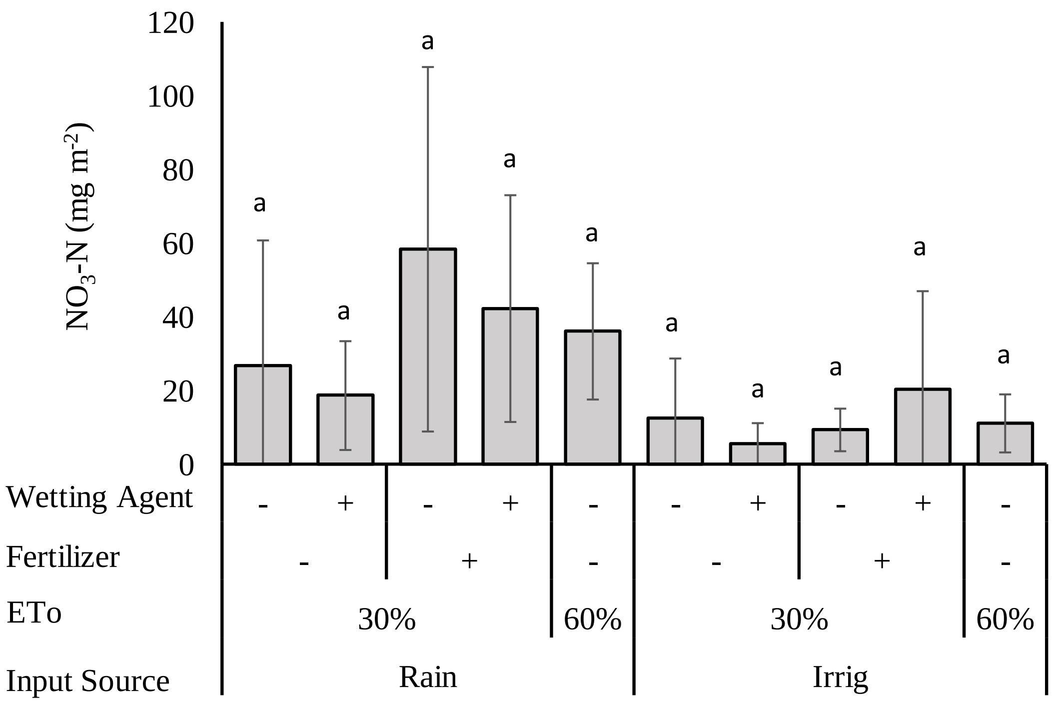


Fig. 3.13. Mean NO_3-N exports in runoff water. Error bars represent the standard deviation. - represents no addition of amendment and + represents addition of amendment. Lower case letters indicate no significant differences among treatments.

3.5.2 Orthophosphate-P

PO_4-P exports ranged from 14.7± mg m^{-2} in the irrigation induced runoff for the 30-0-1 treatment to 1179±763.9 mg m^{-2} in the rainfall induced runoff for the 30-1-0 treatment (Fig. 3.14). Univariate analysis of variance determined that there was a significant effect of runoff induced water source ($p < 0.001$), fertilizer application ($p = 0.034$) and a significant interaction between water source and fertilizer ($p = 0.04$) on PO_4-P exports (Table 3.8). There was an effect of ET_o ($p = 0.064$) and interaction effect of water source and ET_o ($p = 0.066$) on PO_4-P exports but these were not significant (Table 3.9). There was no significant effect of wetting agent on PO_4-P exports (Fig. 3.14).

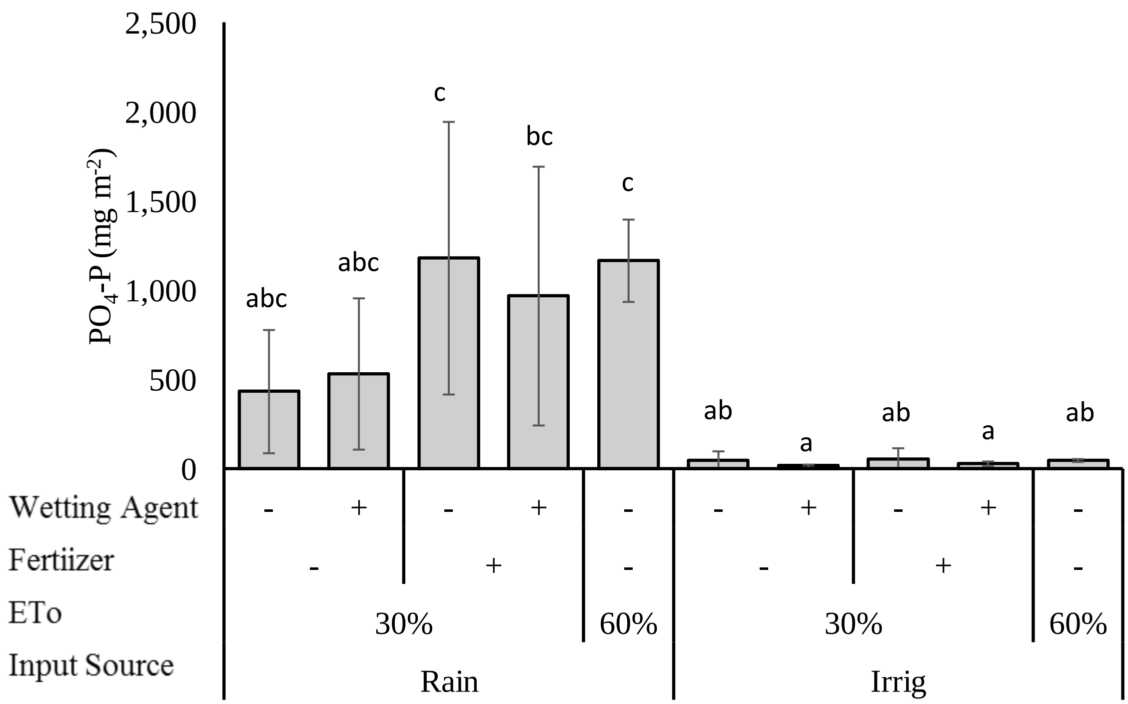


Fig. 3.14. Mean PO_4-P exports in runoff water. Error bars represent the standard deviation. - represents no addition of amendment and + represents addition of amendment. Different lower case letters indicate significant differences among treatments.

Table 3.8 ANOVA of main effects on exports of inorganic N and P. Bold values indicate significant effects at alpha < 0.05.

Main Effects			
	NO_3-N	NH_4-N	PO_4-P
Wetting agent	0.573	0.505	0.759
Fert	0.068	**0.007**	**0.034**
ET_o	0.750	0.250	0.064
H_20 Source	**0.004**	**< 0.001**	**< 0.001**

Table 3.9 ANOVA of interaction effects on exports on inorganic N and P. Bold values indicate significant effects at alpha < 0.05.

Interaction Effects			
	NO_3-N	NH_4-N	PO_4-P
H_20 Source * Et_o	0.669	0.179	0.066
H_20 Source * Fert	0.224	**0.017**	**0.040**
H_20 Source * WA	0.430	0.333	0.914
Fert * WA	0.784	0.649	0.574
H_20 Source* Fert * WA	0.469	0.268	0.566

3.5.3 Soil loss or gain of organic matter and total nitrogen

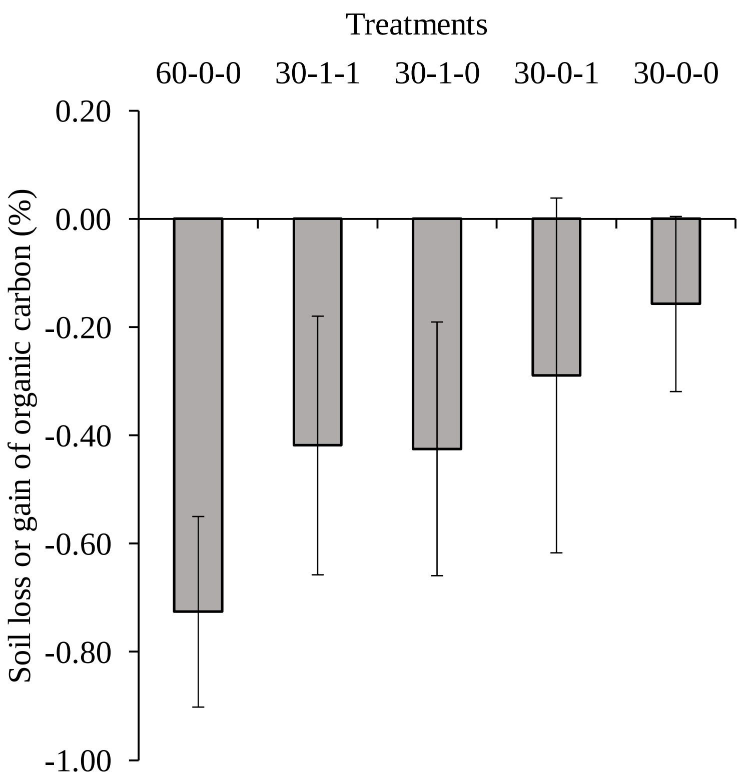


Fig. 3.15. Soil loss or gain of organic carbon. Error bars represent the standard deviation.

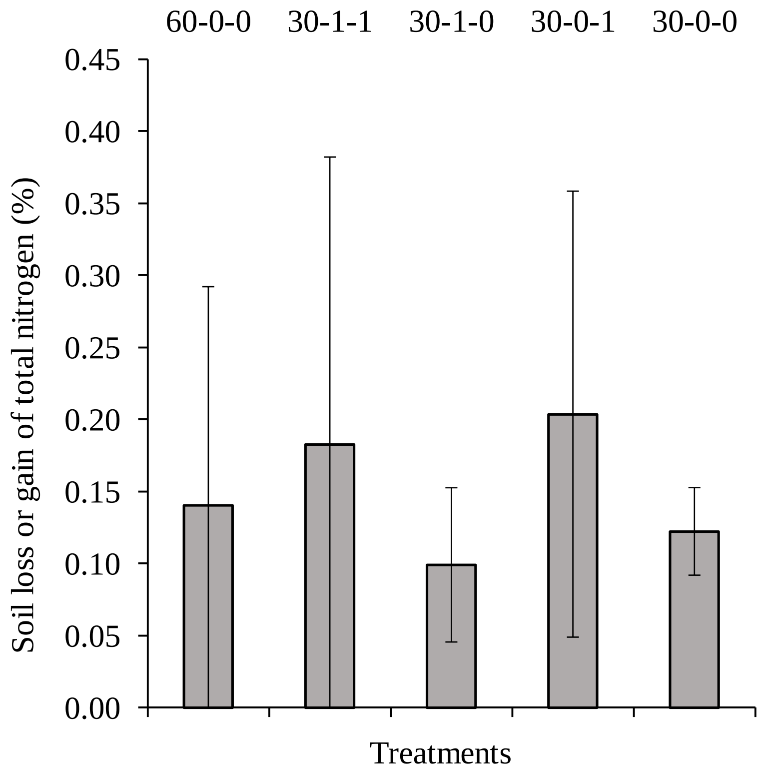


Fig. 3.16. Soil loss or gain of total nitrogen. Error bars represent the standard deviation.

There was an overall loss of soil percent organic carbon (%OC) over the growing season (Fig. 3.15) but this loss was less than 1% of soil OC. Treatment 60-0-0 lost significantly more %OC when compared to treatment 30-0-0 (Fig. 3.16) but there was no significant difference in soil %OC when comparing 60-0-0 with 30-1-1, 30-1-0 or 30-0-1. There was an overall gain of percent total nitrogen (%TN) in the soil over the growing season and this was generally about 0.10-0.20% (Fig.3.16). There was no significant difference in the %TN among treatments.

3.6 Discussion

3.6.1 Effects of wetting agent application on water retention and water runoff

It is important to have infiltration of irrigation water and precipitation to the root zone of residential lawns to ameliorate runoff, ameliorate loss of nutrients, and to maintain green color of the turfgrass. The importance is not only for maintenance of turfgrass, but also for conservation of water, especially under drought conditions. Runoff is an issue after storm events and wasteful irrigation management practices on sloped residential lawns. However, there are several ways to reduce water loss from turfgrass lawns and maximize the amount of water infiltrating the soil including a) reducing evapotranspiration, b) increasing infiltration, c) reducing ponding, and d) controlling water movement. Research has shown that wetting agents increase water infiltration rate, increase time to runoff, and reduce total runoff (Morgan et al. 1966;Mitra et al. 2006). This study sought to examine the effects of a wetting agent on reducing runoff and hence N and P exports from residential lawns with and without fertilizer application and wetting agent. Overall no significant effect of the wetting agent application was observed on N or other exports especially during precipitation induced runoff, due to the high amount of variability within treatment type. In general the plots on block 3 have greater runoff than the plots on block 1 and this will result in the larger variance observed for each treatment combination. The depth of topsoil lying atop a relatively impervious marine massive clay, although showing a range of depths was not significantly different when comparing blocks. One reason for the large variability within treatment may be the extent of preferential flow paths in the massive marine clay layer which would reduce the volume of runoff on certain plots and hence export of N and P. Another factor might be the two different soil series at the facility which have very different soil horizons (Fig. 3.17).

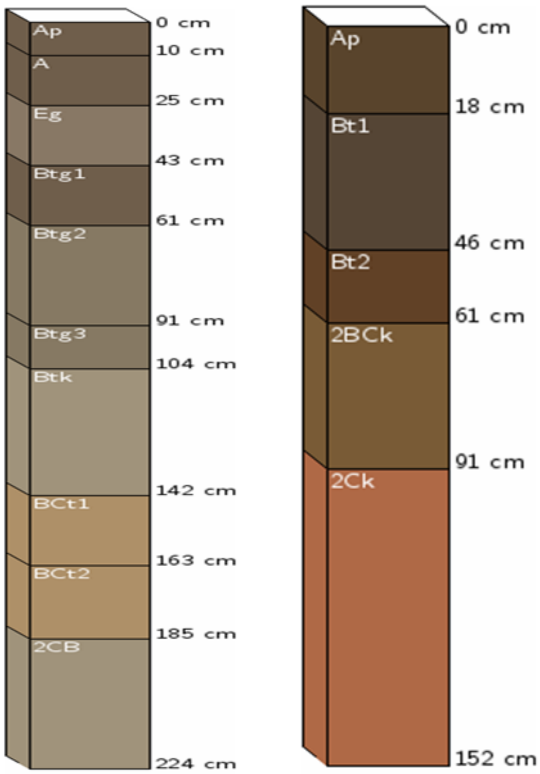


Fig. 3.17. Soil horizons for Boonville (left) and Zack (right) soil series. Source: http://casoilresource.lawr.ucdavis.edu/

The clay layer (45-50% clay) occurs at 43 cm depth in the Boonville soil series and at 18 cm depth in the Zack soil series which would certainly effect time to runoff and runoff volume at the facility and would be responsible for the amount of within treatment variance observed.

The maintenance of green color of turfgrass in residential sub-divisions, particularly those with active home owner associations (HOAs) is deemed very important. All turfgrass in the current study maintained green cover until early August (Fig. 3.18). The treatment with 60% ET_o and no fertilizer or wetting agent amendments kept a higher percent green cover for most of the study period relative to the other treatments (Fig. 3.18), but by the beginning of October 2015 all treatments had percent green cover of ~50% (Fig. 3.18). Generally, when examining the fertilized treatments with or without wetting agent, the 30-1-1 treatment performed slightly better than the 30-1-0 treatment during the drought conditions of August, 2015 (Fig. 3.18) but prior to and after August 2015 there was no observable difference in percent combined green cover between these treatments (Fig. 3.18). Examining the unfertilized treatments with or without wetting agent, the 30-0-1 treatment performed better at maintaining percent green cover than the 30-0-0 treatment for the period between the end of July and end of August 2015 (Fig. 3.18).

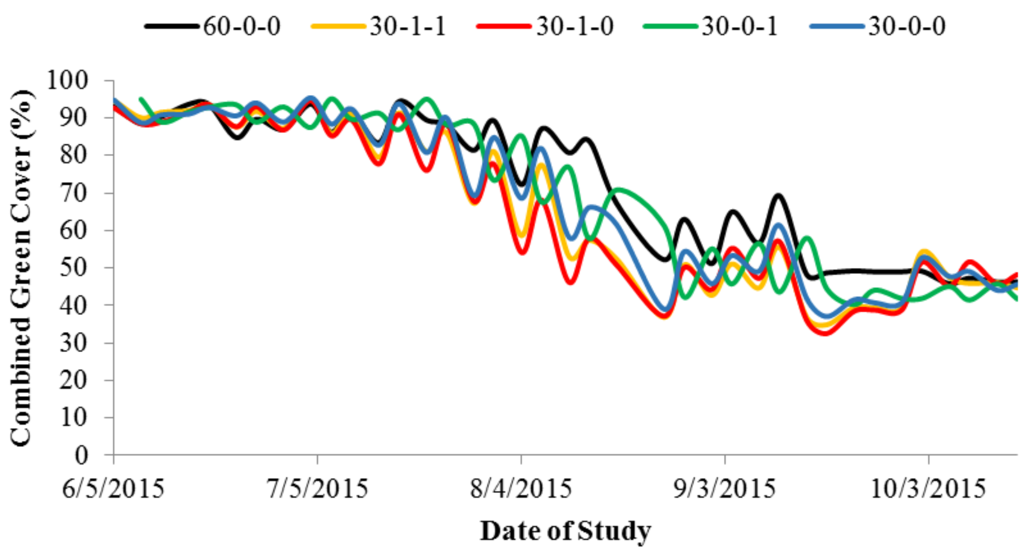


Fig. 3.18. Percent of combined green cover for the combined ET_o, fertilized and wetting agent treatments.

Percent green cover on plots may give some insight into the observed exports of N and P and lack of significant effect of wetting agent on exports. For example, greater green cover will act as an enhanced interceptor of incoming precipitation or irrigation water which will slow the rate of travel to the soil and may have greater potential for evapotranspiration. Thus, the potential for enhanced runoff from plots with a greater percent of combined green cover is much less than from plots with less green cover (Karcher and Richardson 2003).

Wetting agents have been shown to increase the vertical movement of water in the soil profile, thus increasing the water retention capacity of a loamy sand soil (Mitra et al. 2006). A loamy sand soil situated on an 8% slope with an established turfgrass maintained under golf course fairway management conditions did not have appreciable runoff until 45 minutes of irrigation runtime, reducing total runoff by 30% (Mitra et al. 2006). Compared to our 3% slope on St. Augustine grass plots, which had appreciable observed runoff after about 20 minutes of a forced irrigation event, particularly for the plots located on the Zack soil series, the loamy sand soil in the Mitra et al. (2006) study retained water for longer. Loamy sands typically have 70-85% sand whereas in the current study, soil was a sandy loam which typically have 50-70% sand. However, a study in a California forested area that was burned over by a wildfire showed a 32% reduction in runoff after the application of a wetting agent on a very hydrophobic sandy loam texture with an average slope of 65% (Osborn et al. 1964).

Research has found an increase in soil hydrophobicity with particle size within a soil sample (Crockford et al. 1991). Sand textured soils are more susceptible to developing hydrophobicity due to their small surface area (444.4 $cm^2\ g^{-1}$) as compared to the large surface area of a clay ($7.4 \times 10^6\ cm^2\ g^{-1}$) (Doerr et al. 2000). Sand is known to have low water holding capacity and poor ability to store plant nutrients which becomes more evident as sand percent increases in a soil. Even though wetting agents have been shown to improve water retention and decrease runoff this may be a case of known soil hydrophobicity in the soils tested whereas the soils in the current study have not displayed hydrophobicity. A water drop penetration time test was conducted on the soils at the runoff facility to determine the repellency of the soil for this study. The shortest time measured was 0.1 s which corresponds to instantaneous penetration and non-repellent soils (Leelamanie et al. 2008).

3.6.2 Effect of wetting agent application on water runoff export analytes

In our study the application of wetting agent had no significant effect on inorganic nitrogen and orthophosphate losses to runoff. Although insignificant, 30-0-1 treatment had lower mean exports of NH_4-N and NO_3-N in irrigation water source when compared to other treatments. A study by Arriaga et al. (2009) had 30.1% less soil NO_3-N soil concentrations 20 days after the last N fertilization with wetting agent application on loamy sand soil and similarly decreased soil NH_4-N concentrations; attributed this to a more uniform distribution of the applied N or/and increased plant use of the applied N over a three year period.

3.7 Conclusion

The use of wetting agents has relieved sandy soils across the world from water repellency which is a major factor contributing to increased losses of water and nutrients. However, the application of wetting agent on simulated St. Augustine grass had no effect on the percent of retained water volume in the soil, the percent of water runoff, and the exports of nitrate-N, ammonium-N and orthophosphate-P after the collection of rain or forced irrigation events. The degree of soil water repellency will determine the effects that a wetting agent will have on water retention and water runoff as well as the nutrients found in water runoff.

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APPENDIX A

MEAN RUNOFF CHEMISTRY DATA FOR SAMPLES COLLECTED BETWEEN MAY 2013 AND OCTOBER 2014

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
5/9/2013	1	7.47	521.94	3.12	2.32	3.95	34.71	14.57	9.13	73.84	33.21	1.49	15.50
5/9/2013	2	7.59	342.71	2.60	1.24	3.99	35.65	11.98	8.14	60.79	20.10	0.69	4.10
5/9/2013	3	7.50	382.64	4.11	1.62	4.21	34.63	14.16	8.43	60.22	25.11	1.02	5.60
5/9/2013	4	7.54	380.31	1.27	1.66	4.03	42.83	13.83	10.90	65.91	23.74	0.68	3.55
5/9/2013	5	7.79	360.53	0.53	0.28	4.31	37.20	3.20	2.39	70.41	18.43	0.66	4.24
5/9/2013	6	7.75	408.51	3.32	1.40	4.58	59.42	13.74	9.03	71.65	25.28	0.74	3.91
5/9/2013	7	7.54	435.10	2.56	4.61	5.30	46.65	16.61	9.44	66.16	30.74	0.82	4.40
5/9/2013	8	7.18	345.29	0.43	0.39	3.99	36.12	3.40	2.58	60.24	18.97	0.60	3.42
5/9/2013	9	7.50	546.41	3.82	8.27	5.46	38.46	18.16	6.07	86.47	32.44	1.24	6.10
5/9/2013	10	7.47	515.63	0.97	6.33	4.78	45.48	15.38	8.07	80.19	29.32	1.06	5.79
5/9/2013	11	7.49	565.01	1.33	9.16	4.89	39.80	18.19	7.70	83.35	34.14	1.14	5.71
5/9/2013	12	7.37	540.78	1.02	9.51	4.80	41.91	17.90	7.37	79.04	31.67	0.91	4.74
5/9/2013	13	7.29	415.63	0.77	7.21	3.10	40.46	13.23	5.25	63.02	20.97	0.60	3.52
5/9/2013	14	7.29	384.63	0.58	0.49	3.36	39.14	3.79	2.73	72.61	16.86	0.63	3.45
5/9/2013	15	7.43	466.07	0.60	7.40	3.22	35.38	12.62	4.63	75.93	21.09	0.71	4.30
5/9/2013	16	7.22	404.10	0.52	0.66	3.36	32.39	3.50	2.32	69.88	19.25	0.61	3.86
5/9/2013	17	7.53	396.47	0.48	8.14	2.99	26.11	13.61	5.00	57.67	20.21	0.62	3.42
5/9/2013	18	7.49	368.70	0.74	6.14	2.71	23.85	9.99	3.11	60.36	15.23	0.53	3.14
5/9/2013	19	7.72	294.16	0.43	1.63	2.75	26.26	10.21	8.16	54.01	13.73	0.45	3.17
5/9/2013	20	7.18	406.57	0.85	6.22	3.27	22.32	9.84	2.77	60.51	20.54	0.74	4.35

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
5/9/2013	21	7.57	311.62	0.59	0.52	3.19	31.29	3.07	1.95	59.89	12.56	0.46	2.54
5/9/2013	22	7.45	438.32	1.12	6.91	3.07	29.34	12.58	4.56	65.24	21.75	0.61	3.55
5/9/2013	23	7.35	359.19	0.32	0.52	3.93	31.95	2.95	2.11	63.16	16.59	0.57	3.37
5/9/2013	24	7.61	388.11	0.89	3.13	3.21	32.37	11.98	7.96	64.97	21.35	0.61	3.42
5/10/2013	1	7.64	462.43	1.21	0.80	2.90	40.60	6.54	4.53	52.07	19.71	2.09	24.78
5/10/2013	2	7.80	377.25	1.27	0.98	3.21	54.42	8.41	6.17	58.21	18.47	1.69	12.38
5/10/2013	3												
5/10/2013	4	7.78	378.38	0.61	0.80	3.25	56.26	9.11	7.71	59.92	20.51	1.52	9.11
5/10/2013	5	7.90	424.34	0.24	0.51	3.29	62.42	6.94	6.19	75.72	18.53	1.62	10.46
5/10/2013	6	7.70	355.43	0.84	0.91	3.29	56.34	7.62	5.87	57.64	19.12	1.29	7.85
5/10/2013	7	7.65	383.53	0.99	1.54	5.23	64.09	8.54	6.02	59.86	27.57	1.51	9.45
5/10/2013	8	7.81	353.57	0.19	1.90	4.59	44.61	7.45	5.37	56.57	17.67	1.25	7.65
5/10/2013	9	7.56	418.60	1.07	0.56	3.61	51.08	7.36	5.71	65.10	20.03	2.24	13.81
5/10/2013	10	7.81	436.25	0.39	0.62	3.23	50.93	6.71	5.70	68.23	22.50	2.26	14.92
5/10/2013	11	7.88	429.48	0.45	0.50	3.08	45.81	5.87	4.93	64.99	26.20	1.79	12.43
5/10/2013	12	7.88	373.62	0.35	0.50	3.19	46.28	6.00	5.16	56.74	21.31	1.66	11.14
5/10/2013	13	7.90	378.22	0.25	0.51	2.99	47.51	7.87	7.10	61.44	18.62	1.30	9.11
5/10/2013	14	7.67	380.43	0.20	0.40	3.15	43.43	4.77	4.16	66.61	15.73	1.48	8.53
5/10/2013	15	7.83	365.60	0.26	0.57	2.86	43.99	6.82	5.99	59.44	16.47	1.41	9.53
5/10/2013	16												
5/10/2013	17	7.75	362.08	0.22	0.43	3.10	36.71	5.83	5.18	49.57	16.86	1.44	10.71
5/10/2013	18	7.84	382.05	0.24	0.50	2.93	38.12	6.53	5.79	58.94	16.12	1.67	12.24
5/10/2013	19	7.89	328.46	0.21	0.51	2.94	33.26	5.29	4.58	52.20	14.06	1.47	9.86
5/10/2013	20												
5/10/2013	21												

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
5/10/2013	22												
5/10/2013	23												
5/10/2013	24	7.90	373.88	0.34	0.61	3.02	48.57	4.62	3.67	56.80	18.83	1.47	9.60
6/2/2013	1	7.35	424.20	0.94	0.56	2.92	32.18	3.88	2.38	65.14	25.00	1.12	9.31
6/2/2013	2	7.33	312.64	1.30	0.58	2.80	36.37	4.48	2.59	57.08	13.52	0.83	4.54
6/2/2013	3	8.10	426.70	1.31	0.46	3.03	45.68	6.07	4.31	66.12	36.64	1.20	5.53
6/2/2013	4	7.61	372.90	0.57	0.70	3.01	50.79	4.15	2.88	65.96	17.06	1.04	6.46
6/2/2013	5	7.42	363.17	0.45	0.76	3.01	49.18	3.78	2.57	66.91	13.99	0.86	5.39
6/2/2013	6	7.33	377.15	1.18	1.13	3.22	46.95	5.12	2.81	60.69	18.67	0.90	6.51
6/2/2013	7	7.56	387.10	0.76	0.82	3.32	49.71	4.70	3.11	59.36	21.82	1.27	6.93
6/2/2013	8	7.81	328.60	0.28	0.57	3.09	39.65	3.04	2.19	49.87	17.01	0.92	5.39
6/2/2013	9	7.35	313.25	0.70	1.98	3.03	38.07	4.32	1.89	54.05	11.46	0.81	4.51
6/2/2013	10	7.25	301.70	0.36	0.45	3.12	32.55	2.36	1.55	49.85	13.06	0.77	4.70
6/2/2013	11	7.69	325.70	0.44	0.49	3.04	31.73	2.96	2.02	58.91	13.83	0.87	6.38
6/2/2013	12	7.20	309.83	0.27	0.65	3.15	29.59	2.42	1.50	55.93	17.40	0.90	5.61
6/2/2013	13	7.81	374.27	0.25	0.52	3.44	52.65	3.64	2.87	65.49	18.40	1.08	6.81
6/2/2013	14	7.91	340.05	0.27	0.85	2.83	48.41	3.41	2.29	113.04	15.41	1.17	7.56
6/2/2013	15	8.03	294.05	0.27	0.37	2.63	38.52	2.50	1.86	103.05	12.89	0.87	5.59
6/2/2013	16	7.67	270.53	0.26	0.37	2.91	26.82	1.99	1.35	46.66	14.77	0.71	4.45
6/2/2013	17	7.47	314.41	0.21	0.44	3.05	35.02	2.21	1.56	56.15	13.65	0.89	6.64
6/2/2013	18	7.36	319.30	0.21	0.39	3.14	36.10	2.53	1.92	57.21	13.24	0.85	4.98
6/2/2013	19	7.29	261.76	0.21	0.46	2.99	29.78	2.34	1.68	47.02	12.87	0.77	4.17
6/2/2013	20	7.32	247.30	0.37	0.69	2.68	25.03	2.57	1.51	45.74	11.90	0.60	5.05
6/2/2013	21	7.86	255.00	0.41	0.51	2.65	29.28	2.78	1.86	102.44	12.49	0.73	3.47
6/2/2013	22	7.14	377.23	0.40	0.60	3.11	41.18	3.91	2.91	62.56	18.61	1.20	6.53

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
6/2/2013	23	7.35	332.15	0.31	0.92	2.99	37.59	3.35	2.13	55.81	12.96	0.81	5.25
6/2/2013	24	7.43	371.93	0.28	2.58	3.67	49.46	5.80	2.94	64.45	18.62	1.12	5.37
8/13/2013	1	8.87	1143.43	2.59	0.27	2.23	28.01	4.95	2.09	262.65	18.94	1.39	5.27
8/13/2013	2	8.81	1066.00	0.47	0.15	1.23	23.76	2.73	2.11	263.10	12.88	0.96	5.20
8/13/2013	3	9.18	1226.00	0.97	0.17	2.67	28.88	3.69	2.54	295.55	17.39	0.87	4.15
8/13/2013	4	9.02	1131.00	0.89	0.23	1.40	25.37	3.21	2.09	262.21	11.30	1.06	4.36
8/13/2013	5	8.80	1275.20	1.99	0.26	5.14	82.52	8.29	6.04	274.72	28.35	2.20	8.16
8/13/2013	6	9.00	653.87	1.48	0.25	3.14	62.82	7.05	5.31	296.28	24.45	1.54	7.17
8/13/2013	7	9.13	1277.00	1.64	0.32	2.20	40.36	6.90	4.94	294.58	19.14	0.95	5.52
8/13/2013	8	8.98	1205.00	0.54	0.24	4.34	50.73	4.00	3.22	273.60	29.07	1.73	7.39
8/13/2013	9	8.71	1300.33	1.90	0.23	5.48	77.14	8.28	6.15	282.80	31.71	2.10	9.25
8/13/2013	10	8.83	1123.67	0.64	0.30	1.57	42.91	3.84	2.90	264.58	9.81	0.96	5.09
8/13/2013	11	9.10	1505.00	1.30	0.41	3.09	64.31	7.99	6.29	334.86	33.76	2.19	14.66
8/13/2013	12	8.96	1284.33	0.74	0.24	3.68	59.92	6.40	5.42	289.72	28.09	1.39	6.08
8/13/2013	13	8.72	1034.33	0.27	0.19	1.11	19.41	1.61	1.15	248.37	7.68	1.07	4.08
8/13/2013	14	8.58	1268.13	0.28	0.24	6.94	94.42	6.83	6.31	279.30	26.93	2.75	10.93
8/13/2013	15	8.58	1269.67	1.01	0.36	6.43	97.99	8.90	7.54	268.21	33.58	2.58	10.70
8/13/2013	16	9.03	1370.00	0.72	0.26	5.30	64.70	6.74	5.75	317.06	37.05	2.10	8.08
8/13/2013	17	8.75	1197.33	0.42	0.23	3.41	72.06	5.23	4.59	259.46	33.21	1.99	7.96
8/13/2013	18	8.54	1230.40	0.35	0.20	4.62	83.36	5.33	4.77	280.07	26.62	2.08	9.63
8/13/2013	19	8.55	1220.75	0.28	0.20	4.97	64.26	4.74	4.26	268.05	30.83	2.15	8.11
8/13/2013	20	8.68	1187.33	0.65	0.24	5.71	62.25	5.41	4.52	271.64	33.85	2.06	8.25
8/13/2013	21	8.71	1256.25	0.43	0.24	6.16	77.64	6.08	5.41	275.51	33.32	2.26	9.23
8/13/2013	22	8.33	1244.00	2.03	0.23	5.03	55.84	6.52	4.26	285.58	34.91	2.07	7.71
8/13/2013	23	9.17	1144.00	0.71	0.18	2.13	30.15	3.60	2.71	290.77	16.40	0.85	5.45
8/13/2013	24	8.77	1167.00	0.62	0.34	3.48	54.47	6.19	5.23	261.72	19.32	1.19	5.15

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
9/20/2013	1	7.79	523.67	7.35	1.88	10.07	68.99	17.18	7.95	87.44	31.89	1.42	3.88
9/20/2013	2	7.75	306.80	1.72	0.48	7.45	54.26	6.29	4.08	60.86	17.84	0.99	2.68
9/20/2013	3	7.77	299.40	3.25	0.62	7.80	42.66	7.73	3.86	63.56	19.37	0.94	3.15
9/20/2013	4	7.83	345.80	2.67	0.62	7.72	56.15	7.32	4.03	67.12	23.32	1.25	3.37
9/20/2013	5	7.49	405.33	2.97	0.95	8.44	77.66	9.29	5.37	76.84	22.47	1.06	3.58
9/20/2013	6	7.48	392.00	5.02	1.02	6.94	68.83	11.89	5.85	68.57	22.23	0.88	3.37
9/20/2013	7			1.51	0.57	5.02	28.30	4.24	2.16	94.61	27.66	1.26	5.52
9/20/2013	8	7.81	384.60	0.42	0.65	12.34	63.93	5.07	4.00	71.63	25.86	1.24	4.14
9/20/2013	9	7.47	347.80	2.52	0.64	11.24	69.57	8.00	4.84	84.57	23.66	1.36	4.36
9/20/2013	10	7.42	423.00	4.34	0.48	11.50	61.75	9.75	4.93	93.27	31.73	1.58	4.98
9/20/2013	11	7.85	419.00	4.75	0.58	11.80	63.16	10.90	5.58	81.10	27.83	1.67	4.60
9/20/2013	12	7.72	373.60	2.60	0.54	13.08	68.68	7.95	4.81	76.28	23.42	1.33	3.76
9/20/2013	13	7.77	362.40	1.83	0.50	11.33	63.49	6.48	4.14	69.34	22.55	1.33	3.68
9/20/2013	14	7.63	437.83	0.91	0.93	12.39	86.14	8.35	6.50	72.63	26.14	1.46	3.59
9/20/2013	15	7.79	501.67	3.23	0.86	10.82	90.72	11.14	7.05	86.70	27.88	1.34	4.82
9/20/2013	16	7.77	376.80	0.26	0.43	11.28	71.82	4.64	3.95	78.63	25.00	1.39	4.57
9/20/2013	17	7.68	375.60	0.60	0.40	12.22	63.29	4.56	3.57	76.00	22.87	1.12	4.02
9/20/2013	18	7.98	342.67	0.43	0.47	10.54	59.41	4.18	3.29	68.89	20.38	1.00	3.71
9/20/2013	19	7.65	329.60	0.31	0.43	11.29	54.41	3.65	2.90	68.88	17.67	1.02	3.60
9/20/2013	20	7.47	347.60	2.67	0.68	11.19	53.01	7.68	4.34	68.65	21.77	2.25	5.96
9/20/2013	21	7.54	375.20	0.46	0.74	10.72	67.70	5.38	4.17	75.37	16.91	0.97	3.72
9/20/2013	22	7.56	370.57	3.51	0.65	11.11	59.05	9.39	5.23	72.37	29.71	1.63	4.10
9/20/2013	23	7.77	350.20	0.53	0.54	11.66	58.19	4.45	3.39	70.95	22.46	1.27	3.89
9/20/2013	24	7.64	313.40	2.39	0.51	9.69	53.98	6.96	4.06	63.50	24.29	1.12	3.33
9/30/2013	1	7.60	253.00	0.77	2.82	3.40	34.57	7.14	3.56	42.23	25.42	1.59	2.98
9/30/2013	2	7.63	183.20	1.27	0.24	2.73	23.67	2.92	1.41	34.59	10.27	0.45	1.73

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
9/30/2013	3												
9/30/2013	4	7.58	208.20	1.73	0.40	3.13	31.45	4.01	1.88	40.70	16.64	0.99	2.50
9/30/2013	5												
9/30/2013	6	7.54	322.00	3.27	1.04	3.43	41.66	7.30	2.99	57.58	28.69	1.65	3.77
9/30/2013	7	7.55	178.00	1.51	0.54	3.22	28.26	3.86	1.80	33.01	14.71	0.69	2.77
9/30/2013	8	7.76	230.73	0.25	0.35	5.52	34.84	2.36	1.76	44.92	17.75	1.06	3.08
9/30/2013	9	7.97	398.80	2.41	0.29	6.43	52.53	5.95	3.25	78.13	22.25	1.43	4.68
9/30/2013	10	7.61	280.80	2.24	0.23	5.50	41.84	5.09	2.63	55.13	18.94	1.09	3.59
9/30/2013	11	7.77	297.60	2.91	0.24	6.54	48.02	6.12	2.98	50.58	20.49	1.08	3.40
9/30/2013	12	7.93	290.80	1.42	0.22	6.70	51.19	4.53	2.89	61.53	22.03	1.55	4.00
9/30/2013	13	7.80	233.78	1.22	0.32	4.03	34.38	3.42	1.88	45.03	15.42	0.86	2.57
9/30/2013	14	7.67	393.00	0.98	0.41	6.97	59.10	4.76	3.38	80.72	20.36	1.33	5.14
9/30/2013	15	7.72	401.40	1.90	0.41	5.42	48.53	5.22	2.91	73.01	21.46	1.37	4.26
9/30/2013	16	7.69	345.80	0.23	0.31	6.35	56.27	3.37	2.82	68.53	20.71	1.45	4.31
9/30/2013	17	7.68	311.60	0.28	0.19	6.75	49.09	2.90	2.42	65.31	21.43	1.41	4.11
9/30/2013	18	7.68	314.60	0.38	0.21	6.13	43.66	2.70	2.10	63.79	15.82	1.30	3.77
9/30/2013	19	7.90	292.20	0.28	0.21	6.75	45.28	2.69	2.20	57.75	18.35	1.30	3.86
9/30/2013	20	7.53	238.18	0.90	0.25	5.28	32.64	3.10	1.96	44.43	18.24	0.87	2.80
9/30/2013	21	7.76	330.00	0.35	1.51	5.92	46.79	4.60	2.75	64.30	18.33	1.11	3.85
9/30/2013	22	7.26	216.07	0.98	0.29	3.84	37.64	3.57	2.29	38.48	16.55	0.74	2.67
9/30/2013	23	7.95	227.78	0.34	0.24	5.31	34.23	2.32	1.74	42.33	14.72	0.63	2.50
9/30/2013	24	7.89	312.80	1.97	0.43	5.12	38.73	4.79	2.38	57.58	24.85	1.19	3.92
10/13/2013	1	7.29	419.40	3.06	1.00	4.89	31.00	6.79	2.73	47.36	22.84	1.46	3.69
10/13/2013	2	7.28	367.40	4.45	0.46	2.83	20.83	6.50	1.59	50.00	18.21	0.95	2.20
10/13/2013	3	7.27	341.20	4.26	0.52	3.41	21.22	6.20	1.43	44.72	20.27	1.06	2.59
10/13/2013	4	7.28	419.00	2.01	1.02	4.23	34.43	5.53	2.50	48.51	20.81	1.03	2.83

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
10/13/2013	5												
10/13/2013	6	7.18	284.00	5.31	0.75	2.77	20.98	7.82	1.75	42.83	18.59	0.84	2.18
10/13/2013	7	7.32	341.00	1.64	0.69	6.03	36.38	4.63	2.31	42.12	22.14	0.91	2.58
10/13/2013	8	7.27	249.20	0.55	0.38	3.79	30.60	2.58	1.65	37.93	15.16	0.81	2.46
10/13/2013	9	7.24	405.20	3.72	0.55	3.58	21.46	5.84	1.56	49.50	17.00	0.87	2.23
10/13/2013	10	7.42	371.20	4.09	0.61	3.54	22.33	6.36	1.65	45.94	17.35	0.89	2.18
10/13/2013	11	7.47	357.20	2.43	0.61	3.05	27.59	4.85	1.81	38.69	15.52	0.75	2.02
10/13/2013	12	7.01	279.80	2.34	0.58	3.63	28.98	4.71	1.79	43.67	16.96	0.79	2.21
10/13/2013	13	7.42	395.00	3.39	0.55	4.14	26.99	5.74	1.81	48.41	18.85	0.97	2.45
10/13/2013	14	7.38	355.80	1.68	0.51	3.21	22.36	3.54	1.35	42.48	11.39	0.70	1.87
10/13/2013	15	7.40	334.40	2.01	0.49	2.65	18.68	3.78	1.29	37.15	11.21	0.60	1.70
10/13/2013	16	7.38	341.20	0.77	0.43	3.29	25.86	2.80	1.60	33.60	12.27	0.63	2.01
10/13/2013	17	7.32	269.22	0.75	0.48	4.29	27.79	2.88	1.66	38.74	15.93	0.69	2.06
10/13/2013	18	7.45	292.40	0.99	0.32	2.94	18.54	2.28	0.97	32.24	9.54	0.45	1.50
10/13/2013	19	7.36	255.20	0.56	0.31	3.28	19.08	1.86	0.98	32.56	10.41	0.59	1.71
10/13/2013	20	7.28	292.60	2.27	0.38	3.95	21.06	4.05	1.41	46.15	17.87	1.14	2.66
10/13/2013	21	7.40	309.80	0.79	0.36	4.01	23.09	2.55	1.40	39.70	12.58	0.79	2.28
10/13/2013	22	7.37	388.80	1.97	0.60	4.41	26.61	4.32	1.75	46.67	21.45	1.13	2.86
10/13/2013	23	7.54	278.00	0.83	0.42	4.07	24.41	2.63	1.39	37.06	14.16	0.75	2.18
10/13/2013	24	7.26	255.00	2.77	0.51	3.13	17.10	4.36	1.09	39.42	14.74	0.84	2.13
3/10/2014	1			28.75	1.78	8.26	49.27	32.67	2.15	81.85	46.30	4.49	18.55
3/10/2014	2			25.14	1.28	8.08	52.16	29.06	2.64	109.98	45.70	3.74	13.49
3/10/2014	3			28.48	1.10	7.88	48.42	31.81	2.24	92.58	49.87	4.44	15.27
3/10/2014	4			30.81	0.95	7.23	52.46	30.84	0.00	108.25	43.66	4.05	13.87
3/10/2014	5			11.91	1.10	6.16	65.33	16.82	3.82	84.72	20.35	1.89	7.48
3/10/2014	6												

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
3/10/2014	7			30.39	1.98	9.45	47.47	33.69	1.32	91.58	63.86	5.31	18.64
3/10/2014	8			13.66	1.48	10.17	47.51	17.34	2.20	102.98	43.67	3.69	13.56
3/10/2014	9			31.80	1.20	9.00	67.04	36.57	3.57	149.15	45.73	4.84	19.19
3/10/2014	10			35.54	0.97	8.48	55.61	39.53	3.02	152.74	41.35	5.00	18.95
3/10/2014	11			31.90	1.13	8.49	49.77	36.42	3.39	119.09	47.28	5.12	19.99
3/10/2014	12			31.24	1.09	9.22	44.25	34.72	2.39	126.92	46.78	4.89	19.07
3/10/2014	13			28.24	1.00	9.15	54.48	31.76	2.53	120.03	42.41	4.77	15.85
3/10/2014	14			17.27	0.89	8.78	70.59	22.37	4.21	97.72	22.00	2.07	7.73
3/10/2014	15			15.12	0.77	7.37	50.18	18.27	2.37	143.18	35.46	2.74	10.38
3/10/2014	16			8.15	0.72	9.30	60.74	12.21	3.35	116.03	32.70	3.24	12.30
3/10/2014	17			18.85	1.18	11.28	67.24	22.71	2.68	95.34	28.61	3.00	11.63
3/10/2014	18			14.69	1.35	11.52	80.06	18.65	2.61	117.71	29.13	3.65	11.99
3/10/2014	19			13.21	1.07	11.41	62.15	17.68	3.40	110.71	35.81	4.48	16.56
3/10/2014	20			28.19	1.66	9.83	52.99	32.37	2.52	121.81	50.13	4.62	18.29
3/10/2014	21			19.60	0.88	10.83	67.78	24.71	4.23	146.19	45.52	4.63	15.73
3/10/2014	22												
3/10/2014	23			22.68	1.08	10.55	64.35	27.05	3.28	117.94	48.17	4.27	15.88
3/10/2014	24			26.90	1.43	8.69	52.33	30.95	2.63	108.96	47.60	4.02	15.58
3/24/2014	1												
3/24/2014	2												
3/24/2014	3												
3/24/2014	4												
3/24/2014	5												
3/24/2014	6												
3/24/2014	7			15.38	1.05	4.07	84.22	15.39	0.00	213.08	43.53	6.51	19.04
3/24/2014	8												

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
3/24/2014	9			15.11	0.66	4.04	99.17	17.42	1.65	260.99	37.78	5.97	19.11
3/24/2014	10			13.85	0.85	3.18	96.47	15.02	0.32	252.91	32.02	5.54	17.13
3/24/2014	11			18.80	0.55	3.99	90.88	19.35	0.00	233.83	35.01	6.24	21.77
3/24/2014	12			15.20	0.58	3.40	89.95	16.27	0.49	240.04	35.30	5.82	19.71
3/24/2014	13			11.94	0.79	3.38	89.44	13.05	0.38	241.88	32.74	5.00	16.06
3/24/2014	14												
3/24/2014	15												
3/24/2014	16												
3/24/2014	17												
3/24/2014	18												
3/24/2014	19												
3/24/2014	20												
3/24/2014	21												
3/24/2014	22												
3/24/2014	23												
3/24/2014	24												
5/9/2014	1	6.95	1275.60	10.33	1.06	2.87	39.24	11.97	0.58	90.74	30.01	22.18	155.07
5/9/2014	2	7.32	1123.80	5.47	0.51	2.21	33.85	6.86	0.88	93.74	20.92	15.96	120.77
5/9/2014	3	6.97	1171.50	6.31	0.53	2.18	32.15	7.49	0.65	80.23	25.34	20.11	150.02
5/9/2014	4	7.18	1131.00	3.39	0.38	1.67	28.55	4.63	0.85	72.96	18.08	14.44	153.68
5/9/2014	5	7.36	1219.60	2.14	0.40	1.35	33.30	3.73	1.19	105.79	20.83	13.70	146.77
5/9/2014	6	7.22	1124.00	3.05	0.43	1.56	30.13	4.46	0.99	86.56	19.63	13.79	149.95
5/9/2014	7	6.88	1246.60	7.42	0.66	3.04	34.77	8.67	0.59	90.64	32.62	20.44	158.66
5/9/2014	8	7.10	1071.40	2.70	0.51	2.80	33.36	4.68	1.47	88.05	23.48	14.73	120.82
5/9/2014	9	7.61	1895.80	6.17	0.38	1.94	73.02	6.94	0.96	220.75	26.53	16.59	174.66
5/9/2014	10	8.36	1346.00	3.70	0.41	2.00	31.85	5.15	1.04	99.44	20.14	16.64	182.38

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
5/9/2014	11	8.41	1204.50	7.48	0.48	2.61	37.00	8.49	0.53	100.20	27.32	19.54	180.09
5/9/2014	12	8.40	1253.00	5.62	0.49	2.59	35.42	6.75	0.64	96.58	24.48	18.83	178.22
5/9/2014	13	8.42	1077.40	3.66	0.41	2.16	32.14	4.89	0.99	86.71	21.25	16.32	149.59
5/9/2014	14	6.67	1449.20	2.80	0.37	1.87	47.72	4.30	1.13	139.18	19.51	13.95	165.32
5/9/2014	15	7.62	1404.80	2.06	0.58	1.63	47.43	4.20	1.56	148.57	21.87	13.65	149.86
5/9/2014	16	7.12	1154.75	1.97	0.33	3.07	40.35	3.95	1.65	106.60	29.31	13.54	115.46
5/9/2014	17	7.14	1241.20	3.06	0.49	2.89	38.15	4.98	1.42	107.08	27.80	17.61	139.44
5/9/2014	18	7.29	1270.20	2.94	0.36	2.33	38.40	4.63	1.34	119.19	22.84	16.07	146.26
5/9/2014	19	8.29	1230.33	2.80	0.39	2.66	34.90	4.42	1.23	99.68	24.68	17.97	151.24
5/9/2014	20	8.26	1105.60	3.57	0.44	2.46	32.47	5.10	1.09	87.95	21.33	14.49	141.32
5/9/2014	21	8.48	1013.40	1.94	0.43	2.11	29.15	3.48	1.11	84.58	17.69	12.35	121.43
5/9/2014	22	8.42	1153.25	5.03	0.53	2.73	33.41	6.58	1.02	84.42	25.02	16.29	144.08
5/9/2014	23	7.62	1225.00	3.81	0.88	2.76	39.92	6.25	1.57	105.29	27.22	16.47	147.32
5/9/2014	24	6.98	1003.00	3.73	0.57	2.20	38.69	5.73	1.43	91.20	20.61	12.21	109.82
5/13/2014	1	7.25	771.40	3.70	0.38	1.91	27.69	5.15	1.07	39.31	17.33	10.95	109.22
5/13/2014	2	7.67	905.00	2.02	0.27	1.64	25.09	3.16	0.87	43.75	13.47	12.06	137.08
5/13/2014	3	7.50	1049.20	1.97	0.26	1.62	23.48	2.93	0.70	36.81	17.56	15.87	177.67
5/13/2014	4	7.49	975.00	1.36	0.27	1.61	25.44	2.57	0.94	40.90	13.82	12.13	164.94
5/13/2014	5	7.65	1092.60	0.70	0.31	1.64	28.98	2.01	1.00	73.17	15.16	11.72	154.82
5/13/2014	6	7.44	909.80	1.54	0.28	2.00	26.20	2.83	1.01	51.13	15.56	10.21	131.19
5/13/2014	7	7.33	1384.00	2.00	0.27	2.87	22.96	3.08	0.81	34.90	18.61	14.04	165.47
5/13/2014	8	7.64	793.60	1.21	0.28	3.42	30.37	2.68	1.20	46.30	15.83	9.25	101.81
5/13/2014	9	7.69	749.80	1.41	0.31	2.06	35.07	3.08	1.37	62.95	12.48	6.87	86.00
5/13/2014	10	7.59	1135.60	1.60	0.23	2.24	26.79	2.97	1.13	54.67	15.66	12.50	175.04
5/13/2014	11	7.36	1177.00	2.10	0.27	2.46	25.97	3.46	1.10	46.71	18.48	16.22	210.56
5/13/2014	12												

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
5/13/2014	13	7.49	933.00	0.97	0.29	1.94	26.09	2.33	1.07	48.94	16.00	12.09	146.73
5/13/2014	14	7.46	900.20	0.92	0.26	2.14	30.62	2.45	1.26	64.98	13.41	8.84	128.48
5/13/2014	15	7.69	839.00	0.77	0.25	1.90	30.53	2.18	1.15	55.30	12.81	7.68	107.41
5/13/2014	16	7.67	906.00	0.75	0.29	2.76	39.79	2.65	1.61	67.85	21.20	10.78	107.98
5/13/2014	17	7.42	981.20	0.86	0.30	2.61	27.75	2.20	1.04	52.34	17.65	13.48	151.86
5/13/2014	18	7.52	901.20	1.14	0.28	2.28	24.54	2.63	1.20	57.98	15.02	11.14	138.50
5/13/2014	19	7.41	907.50	0.70	0.25	2.23	22.69	2.05	1.11	50.36	14.56	12.09	145.77
5/13/2014	20	7.53	924.20	1.06	0.23	2.29	21.58	2.30	1.02	42.02	13.92	11.97	164.57
5/13/2014	21	7.45	809.60	0.60	0.24	2.08	20.51	1.65	0.81	44.68	14.06	9.41	120.79
5/13/2014	22	7.51	1022.20	1.57	0.25	2.36	18.06	2.36	0.62	41.11	17.94	13.95	184.13
5/13/2014	23	7.61	978.60	0.95	0.29	2.59	18.91	1.75	0.73	49.24	16.40	13.13	164.93
5/13/2014	24	7.54	737.20	1.37	0.28	2.17	25.64	3.07	1.42	49.34	15.15	9.85	118.44
5/27/2014	1	7.44	406.00	8.27	0.90	1.93	31.51	15.33	6.15	29.21	15.73	6.08	56.86
5/27/2014	2	7.46	424.40	5.82	0.87	1.52	29.77	15.27	8.57	26.18	10.25	3.89	40.36
5/27/2014	3	7.15	455.60	5.80	0.61	1.65	28.08	13.53	7.12	27.22	15.71	6.72	65.22
5/27/2014	4	7.37	407.40	4.13	0.68	1.35	27.81	12.27	7.46	28.22	13.04	4.58	50.74
5/27/2014	5	7.59	490.20	1.03	0.26	1.29	28.35	6.03	4.74	48.24	9.55	5.20	53.80
5/27/2014	6	7.48	455.20	4.42	0.66	1.32	28.47	12.50	7.42	31.58	12.47	3.73	45.48
5/27/2014	7	7.31	549.00	5.76	0.91	1.96	28.53	14.42	7.74	26.97	16.67	6.02	66.92
5/27/2014	8	7.39	357.00	1.33	0.44	2.21	28.11	3.51	1.74	34.10	9.40	3.43	34.76
5/27/2014	9	7.25	432.20	6.80	1.02	1.77	29.73	15.16	7.34	38.80	12.39	3.31	36.97
5/27/2014	10	7.45	634.40	5.96	0.77	1.69	27.97	13.63	6.90	35.43	14.48	5.56	72.23
5/27/2014	11	7.13	633.00	5.69	0.77	1.71	28.66	14.01	7.55	28.92	16.45	8.16	102.28
5/27/2014	12	7.48	621.80	5.74	0.85	1.85	29.89	15.63	9.05	32.17	16.68	6.50	90.92
5/27/2014	13	7.35	415.60	3.46	0.74	1.58	28.36	12.58	8.38	30.23	15.37	4.57	55.66
5/27/2014	14	7.48	357.00	1.09	0.34	1.79	26.02	2.74	1.30	38.19	8.46	2.87	37.90

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
5/27/2014	15	7.46	401.20	4.39	0.85	1.65	30.92	13.22	7.98	40.19	16.44	4.02	47.22
5/27/2014	16	7.15	346.60	0.91	0.25	2.64	28.62	2.50	1.35	33.51	13.56	3.73	38.59
5/27/2014	17	7.17	522.20	4.35	0.97	2.40	34.96	14.64	9.32	38.65	18.50	5.93	64.31
5/27/2014	18	7.31	460.20	4.24	0.95	2.21	33.43	13.44	8.25	34.51	13.50	4.25	50.15
5/27/2014	19	7.18	440.20	3.53	0.96	2.18	32.94	14.84	10.35	38.24	20.06	4.71	55.62
5/27/2014	20	7.31	396.40	3.59	0.69	1.74	27.90	11.63	7.35	28.69	13.52	3.73	46.66
5/27/2014	21	7.43	377.80	1.06	0.29	1.86	23.12	2.47	1.12	32.97	9.89	3.68	42.59
5/27/2014	22	7.34	446.80	4.55	0.67	1.76	28.69	12.86	7.63	25.23	15.57	3.92	50.93
5/27/2014	23	7.37	409.00	1.57	0.33	2.11	24.90	2.94	1.04	28.55	9.86	3.90	44.54
5/27/2014	24	7.33	403.80	6.67	1.08	1.95	30.47	14.87	7.58	32.31	15.70	4.31	44.79
5/28/2014	1	7.22	245.50	1.81	0.30	1.53	29.10	4.62	2.51	18.92	9.31	3.84	34.71
5/28/2014	2	7.32	216.50	1.05	0.23	1.10	24.39	3.69	2.40	15.39	5.85	2.07	22.27
5/28/2014	3	7.04	290.75	1.38	0.22	1.17	23.34	3.85	2.25	15.46	8.49	3.68	38.96
5/28/2014	4	6.86	288.25	1.10	0.24	1.05	24.88	4.08	2.73	17.80	8.00	3.71	39.61
5/28/2014	5	7.13	397.25	0.31	0.19	1.16	28.03	1.39	0.89	25.02	5.37	3.21	37.17
5/28/2014	6	7.11	269.50	1.10	0.20	1.05	25.03	3.62	2.32	16.99	6.75	2.05	24.64
5/28/2014	7	6.83	336.25	1.52	0.27	1.44	22.42	4.17	2.38	18.72	11.95	4.82	45.14
5/28/2014	8	7.15	324.00	0.39	0.25	2.09	30.46	1.91	1.28	26.07	8.37	4.20	35.27
5/28/2014	9	7.20	263.75	1.41	0.24	1.65	27.13	4.22	2.56	26.23	7.89	1.84	19.30
5/28/2014	10	7.33	439.00	1.12	0.51	1.56	27.65	4.70	3.08	30.22	10.51	5.08	58.09
5/28/2014	11	7.19	459.75	1.26	0.28	1.50	25.42	4.56	3.02	22.87	12.28	6.57	82.95
5/28/2014	12	6.94	399.00	1.14	0.28	1.32	24.69	4.30	2.88	19.06	7.98	3.57	49.42
5/28/2014	13	7.16	250.00	0.92	0.22	1.21	22.84	3.98	2.84	17.92	8.38	3.40	38.47
5/28/2014	14	7.26	200.75	0.41	0.21	1.45	22.84	1.37	0.75	22.48	5.21	2.46	28.22
5/28/2014	15	7.09	264.75	1.09	0.26	1.37	26.00	3.85	2.50	21.43	9.24	2.93	32.59
5/28/2014	16	7.27	262.25	0.30	0.20	2.24	29.58	1.60	1.10	22.83	8.62	3.28	32.02

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
5/28/2014	17	7.11	336.25	1.06	0.30	1.90	28.65	4.37	3.01	23.34	11.23	4.49	46.11
5/28/2014	18	6.86	290.75	1.26	0.26	1.73	26.01	4.23	2.71	24.34	9.91	3.81	40.97
5/28/2014	19	7.26	286.25	0.89	0.25	1.74	26.00	3.81	2.67	17.12	8.11	3.05	33.91
5/28/2014	20	7.22	256.50	0.98	0.23	1.37	23.34	3.57	2.35	16.95	7.93	3.11	32.96
5/28/2014	21	7.06	249.25	0.39	0.19	1.54	21.78	1.33	0.74	13.77	4.78	2.31	27.42
5/28/2014	22	7.01	305.50	1.20	0.28	1.40	24.50	4.09	2.61	16.16	9.85	3.99	44.86
5/28/2014	23	7.15	246.25	0.46	0.28	1.68	23.14	1.47	0.73	18.29	6.61	3.40	34.53
5/28/2014	24	7.17	214.00	1.50	0.27	1.50	26.65	4.48	2.71	16.59	8.17	2.64	25.50
6/24/2014	1												
6/24/2014	2												
6/24/2014	3												
6/24/2014	4	8.19	1120.00	0.36	0.60	1.97	97.01	2.92	1.97	269.18	6.79	0.96	7.29
6/24/2014	5												
6/24/2014	6												
6/24/2014	7												
6/24/2014	8												
6/24/2014	9	8.32	1191.00	1.02	0.35	1.50	107.01	3.11	1.74	267.56	8.79	1.41	11.45
6/24/2014	10												
6/24/2014	11												
6/24/2014	12												
6/24/2014	13	8.53	1090.00	1.86	0.26	1.40	90.59	3.09	0.97	258.59	11.27	2.32	23.29
6/24/2014	14	7.50	517.80	0.32	0.29	3.40	92.39	5.12	4.50	105.44	16.80	1.03	11.81
6/24/2014	15	7.52	544.85	0.38	0.37	3.26	91.85	5.48	4.73	122.44	19.18	1.11	13.79
6/24/2014	16												
6/24/2014	17												
6/24/2014	18	7.41	580.60	0.23	0.31	5.86	95.04	4.65	4.11	155.09	31.75	1.66	19.39

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
6/24/2014	19												
6/24/2014	20												
6/24/2014	21												
6/24/2014	22												
6/24/2014	23												
6/24/2014	24												
7/5/2014	1												
7/5/2014	2	8.62	1122.00	0.61	1.45	2.41	120.77	6.26	4.20	200.25	27.04	2.71	24.25
7/5/2014	3												
7/5/2014	4												
7/5/2014	5	7.67	1135.00	0.33	0.33	2.47	119.10	3.94	3.28	191.26	27.88	3.03	26.19
7/5/2014	6												
7/5/2014	7												
7/5/2014	8												
7/5/2014	9												
7/5/2014	10												
7/5/2014	11												
7/5/2014	12												
7/5/2014	13												
7/5/2014	14	8.26	1110.00	0.24	0.48	2.93	109.10	3.72	3.00	197.97	22.50	2.63	22.39
7/5/2014	15	7.85	1158.67	1.65	5.88	1.79	112.60	15.94	8.42	189.56	31.26	2.67	24.96
7/5/2014	16												
7/5/2014	17												
7/5/2014	18	8.26	1023.00	0.21	1.55	4.88	114.39	5.57	3.81	195.75	28.99	2.80	25.08
7/5/2014	19												
7/5/2014	20												

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
7/5/2014	21												
7/5/2014	22												
7/5/2014	23												
7/5/2014	24												
7/7/2014	1												
7/7/2014	2												
7/7/2014	3												
7/7/2014	4												
7/7/2014	5												
7/7/2014	6												
7/7/2014	7												
7/7/2014	8												
7/7/2014	9												
7/7/2014	10												
7/7/2014	11												
7/7/2014	12												
7/7/2014	13												
7/7/2014	14												
7/7/2014	15												
7/7/2014	16	8.57	1137.00	0.22	17.45	7.39	151.94	27.16	9.49	159.17	43.41	3.07	26.35
7/7/2014	17												
7/7/2014	18												
7/7/2014	19												
7/7/2014	20												
7/7/2014	21	8.60	1061.00	2.10	0.40	3.06	115.81	6.20	3.70	198.26	25.92	2.68	24.02
7/7/2014	22												

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
7/7/2014	23												
7/7/2014	24												
7/18/2014	1	7.49	143.74	1.20	0.37	1.87	21.37	2.57	1.03	23.26	12.75	0.36	1.96
7/18/2014	2	7.53	155.74	0.53	0.42	2.20	27.12	3.14	2.20	29.24	11.79	0.36	2.43
7/18/2014	3	7.44	155.96	0.84	0.44	2.40	31.12	3.96	2.69	27.17	17.56	0.58	6.52
7/18/2014	4	7.55	171.62	0.57	0.39	2.49	34.37	3.90	2.94	29.56	14.99	0.39	2.30
7/18/2014	5	7.63	164.66	0.44	0.32	2.30	24.33	2.52	1.76	30.69	11.70	0.37	2.22
7/18/2014	6	7.61	164.92	0.73	0.40	2.14	41.22	4.68	3.56	31.74	16.06	0.40	2.64
7/18/2014	7	7.25	129.18	0.46	0.30	2.17	26.04	2.96	2.20	22.86	14.04	0.31	1.63
7/18/2014	8	7.32	162.82	0.36	0.33	2.86	33.70	3.65	2.96	30.03	13.64	0.49	3.13
7/18/2014	9	7.99	148.90	0.64	0.30	2.16	32.36	3.66	2.72	36.30	10.83	0.35	2.19
7/18/2014	10	7.65	158.89	0.60	0.34	2.08	21.02	2.73	1.80	30.88	12.86	0.38	2.45
7/18/2014	11	7.50	153.51	1.01	0.41	2.14	28.17	3.14	1.72	26.48	14.20	0.43	2.64
7/18/2014	12	7.63	162.77	0.70	0.35	2.59	26.20	2.99	1.95	29.93	14.42	0.43	2.47
7/18/2014	13	7.52	164.14	0.38	0.27	2.62	27.09	3.03	2.37	35.14	14.38	0.45	4.67
7/18/2014	14	7.81	147.66	0.34	0.25	2.46	24.36	2.23	1.65	24.05	8.47	0.22	1.59
7/18/2014	15												
7/18/2014	16	7.66	178.98	0.48	0.29	3.17	27.29	2.83	2.07	31.44	15.36	0.64	4.10
7/18/2014	17	7.53	164.63	0.52	0.32	2.90	27.43	3.12	2.27	31.11	14.94	0.46	3.27
7/18/2014	18	7.57	154.97	0.43	0.25	2.62	20.16	2.10	1.42	29.79	10.47	0.39	2.76
7/18/2014	19	7.70	160.04	0.48	0.32	2.64	25.95	2.81	2.02	28.78	15.15	0.40	2.70
7/18/2014	20	7.77	186.80	0.46	0.36	2.53	37.55	4.35	3.53	32.99	14.85	0.46	3.37
7/18/2014	21	7.84	137.58	0.31	0.27	2.43	16.86	1.70	1.13	26.98	11.45	0.39	4.63
7/18/2014	22	7.70	152.80	0.44	0.30	2.00	31.55	3.57	2.83	23.80	13.72	0.34	2.23
7/18/2014	23	7.72	139.32	0.34	0.27	2.73	20.91	2.08	1.47	28.56	13.78	0.35	2.26
7/18/2014	24	7.66	145.78	0.43	0.30	1.99	30.80	3.50	2.77	23.89	11.29	0.30	1.83

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
9/15/2014	1	7.27	170.50	0.93	0.92	4.48	23.70	3.54	1.70	26.89	12.97	0.26	1.18
9/15/2014	2	7.37	144.00	0.31	0.44	3.75	18.18	1.91	1.16	23.38	6.42	0.16	0.80
9/15/2014	3	7.27	148.75	0.47	0.49	2.73	18.91	2.19	1.23	25.54	10.32	0.23	1.11
9/15/2014	4	7.32	146.00	0.46	0.57	5.48	18.78	2.34	1.31	22.51	8.48	0.15	0.97
9/15/2014	5	7.39	204.20	0.29	0.51	2.84	25.42	2.26	1.45	34.38	9.21	0.15	1.48
9/15/2014	6	7.80	436.20	0.62	0.63	2.36	38.22	3.51	2.26	77.91	10.93	0.68	3.58
9/15/2014	7	7.62	365.80	0.65	1.43	3.33	29.35	4.74	2.66	24.17	8.83	0.20	1.43
9/15/2014	8	6.86	156.60	0.25	0.56	5.82	23.91	2.25	1.44	29.36	8.17	0.22	1.23
9/15/2014	9	7.38	181.56	0.44	0.54	2.41	23.38	2.49	1.51	26.87	6.95	0.13	1.01
9/15/2014	10	7.59	182.20	0.62	0.53	4.60	23.36	2.77	1.62	27.56	8.43	0.18	1.01
9/15/2014	11	7.49	206.20	1.48	0.61	3.19	24.43	3.97	1.88	29.71	11.18	0.24	1.59
9/15/2014	12	7.51	177.20	1.05	0.62	4.09	22.61	3.24	1.57	28.22	11.33	0.20	1.43
9/15/2014	13	7.43	151.60	0.30	0.46	4.60	18.57	1.90	1.14	33.30	8.63	0.20	1.28
9/15/2014	14	7.49	229.00	0.29	0.67	3.10	29.84	2.79	1.83	39.35	8.98	0.32	1.74
9/15/2014	15	7.51	248.20	0.43	0.53	5.16	27.91	2.75	1.79	40.45	8.75	0.20	1.45
9/15/2014	16	7.09	201.00	0.42	0.50	4.24	31.47	2.75	1.83	28.90	8.86	0.25	1.46
9/15/2014	17	6.00	179.40	0.60	0.49	5.59	24.42	2.73	1.64	25.51	9.34	0.23	1.24
9/15/2014	18	7.61	227.20	0.33	0.49	4.37	28.02	2.47	1.66	38.39	8.58	0.19	1.50
9/15/2014	19	7.57	175.20	0.36	0.51	3.88	23.91	2.36	1.49	27.74	7.92	0.12	1.26
9/15/2014	20	7.63	164.80	0.32	0.34	4.04	19.34	1.94	1.28	27.50	8.36	0.11	1.16
9/15/2014	21	7.59	182.40	0.26	0.45	4.56	22.84	2.04	1.33	25.47	6.04	0.24	1.04
9/15/2014	22	7.49	171.80	0.46	0.57	4.25	23.60	2.64	1.60	26.25	9.77	0.23	1.23
9/15/2014	23	7.61	149.20	0.26	0.38	4.95	16.97	1.56	0.92	24.81	7.61	0.14	0.95
9/15/2014	24	7.59	138.60	0.29	0.33	3.49	15.54	1.55	0.93	23.47	5.97	0.17	1.03
10/13/2014	1												
10/13/2014	2												

Date	Plot #	pH	EC us cm-1	NO_3-N mg/L	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
10/13/2014	3												
10/13/2014	4												
10/13/2014	5												
10/13/2014	6												
10/13/2014	7												
10/13/2014	8												
10/13/2014	9												
10/13/2014	10	7.10	120.50	1.70	0.59	5.48	50.37	5.97	3.69	62.34	19.63	1.15	5.45
10/13/2014	11												
10/13/2014	12												
10/13/2014	13	6.97	103.70	0.57	0.56	3.00	53.66	3.94	2.81	58.62	16.64	0.78	4.54
10/13/2014	14	6.77	109.60	0.52	0.48	5.61	60.12	4.04	3.04	89.60	19.91	1.02	5.76
10/13/2014	15	7.15	113.15	0.92	0.39	3.42	48.51	4.47	3.16	71.11	19.11	0.88	5.20
10/13/2014	16	7.50	100.03	0.36	0.27	6.09	49.27	3.25	2.62	43.35	16.49	0.34	3.85
10/13/2014	17	8.05	269.90	0.54	0.38	5.15	47.83	3.48	2.56	78.02	19.01	0.97	5.40
10/13/2014	18	8.06	249.70	0.31	0.26	4.90	32.12	2.18	1.61	38.67	18.31	0.24	3.21
10/13/2014	19												
10/13/2014	20												
10/13/2014	21	6.92	98.48	0.66	0.56	2.97	60.61	5.05	3.83	68.03	21.40	1.32	6.69
10/13/2014	22												
10/13/2014	23												
10/13/2014	24												

APPENDIX B

ANALYTE EXPORTS FOR SAMPLES COLLECTED BETWEEN MAY 2013 AND OCTOBER 2014

Date	Plot #	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg m^{-2} $event^{-1}$					
5/9/2013	1	113.0	84.1	143.1	1257.5	527.7	330.6	2675.2	1203.1	54.0	561.4
5/9/2013	2	105.6	50.3	162.1	1448.4	486.7	330.8	2469.9	816.5	28.1	166.7
5/9/2013	3	144.1	56.8	147.7	1214.5	496.5	295.6	2111.7	880.6	35.9	196.3
5/9/2013	4	64.2	83.6	203.0	2159.2	697.1	549.3	3323.1	1196.8	34.4	178.9
5/9/2013	5	29.4	15.3	237.6	2049.0	176.2	131.5	3878.4	1015.5	36.5	233.4
5/9/2013	6	151.5	63.7	208.8	2711.1	626.9	411.8	3269.1	1153.4	33.9	178.2
5/9/2013	7	80.3	144.4	166.2	1462.4	520.6	295.9	2074.2	963.7	25.7	137.9
5/9/2013	8	14.5	13.4	136.1	1232.3	115.9	88.0	2055.0	647.1	20.6	116.7
5/9/2013	9	495.6	1074.3	709.3	4994.0	2358.0	788.1	11226.1	4212.0	161.5	792.1
5/9/2013	10	91.4	593.9	447.9	4265.7	1442.1	756.9	7520.4	2749.5	99.3	543.3
5/9/2013	11	103.4	713.5	380.6	3099.1	1416.7	599.8	6490.6	2658.5	89.0	444.6
5/9/2013	12	96.2	900.6	454.3	3968.3	1694.6	697.8	7483.3	2998.8	85.9	448.5
5/9/2013	13	34.8	323.9	139.2	1818.2	594.7	236.0	2832.2	942.5	27.2	158.2
5/9/2013	14	52.5	44.0	303.3	3533.2	342.6	246.1	6555.0	1521.9	57.3	311.4
5/9/2013	15	42.5	528.1	229.8	2525.6	901.1	330.5	5420.2	1505.7	50.4	307.0
5/9/2013	16	29.7	37.8	192.4	1852.5	200.1	132.6	3997.2	1101.0	35.1	220.7
5/9/2013	17	15.9	271.4	99.6	870.7	453.8	166.6	1922.8	673.9	20.6	114.0
5/9/2013	18	33.1	273.0	120.7	1061.4	444.7	138.6	2685.7	677.7	23.6	139.7
5/9/2013	19	13.0	49.7	84.1	802.1	312.0	249.2	1649.7	419.4	13.7	96.7
5/9/2013	20	26.7	195.8	103.1	703.0	309.9	87.4	1906.1	647.0	23.4	136.9

Date	Plot #	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg m^{-2} $event^{-1}$					
5/9/2013	21	18.8	16.8	102.3	1004.2	98.4	62.7	1922.1	403.1	14.6	81.6
5/9/2013	22	46.5	287.9	128.0	1222.7	524.4	190.0	2718.8	906.3	25.5	147.8
5/9/2013	23	10.3	16.6	126.1	1025.3	94.6	67.8	2027.1	532.5	18.4	108.3
5/9/2013	24	27.7	97.6	99.9	1008.1	373.2	248.0	2023.5	664.8	19.1	106.6
5/10/2013	1	6.1	4.1	14.7	206.0	33.2	23.0	264.2	100.0	10.6	125.8
5/10/2013	2	6.3	4.9	16.0	271.1	41.9	30.7	290.0	92.0	8.4	61.7
5/10/2013	3										
5/10/2013	4	2.4	3.2	13.1	226.1	36.6	31.0	240.8	82.4	6.1	36.6
5/10/2013	5	2.1	4.6	29.2	553.7	61.5	54.9	671.6	164.4	14.3	92.8
5/10/2013	6	4.1	4.4	16.0	274.7	37.1	28.6	281.0	93.2	6.3	38.3
5/10/2013	7	3.4	5.3	18.0	220.3	29.4	20.7	205.8	94.8	5.2	32.5
5/10/2013	8	0.6	5.9	14.2	138.5	23.1	16.7	175.7	54.9	3.9	23.8
5/10/2013	9	8.3	4.4	28.0	396.0	57.0	44.2	504.7	155.3	17.3	107.1
5/10/2013	10	3.9	6.2	32.3	509.4	67.1	57.0	682.4	225.0	22.6	149.2
5/10/2013	11	3.1	3.4	21.1	314.1	40.3	33.8	445.6	179.6	12.3	85.2
5/10/2013	12	2.8	4.1	26.1	379.8	49.3	42.4	465.6	174.9	13.6	91.4
5/10/2013	13	1.7	3.5	20.4	323.8	53.6	48.4	418.7	126.9	8.8	62.1
5/10/2013	14	2.6	5.2	40.4	557.0	61.2	53.4	854.2	201.8	19.0	109.4
5/10/2013	15	2.0	4.4	22.0	338.5	52.5	46.1	457.4	126.7	10.9	73.4
5/10/2013	16										
5/10/2013	17	1.6	3.2	22.6	267.1	42.4	37.7	360.6	122.6	10.5	77.9
5/10/2013	18	2.3	4.8	28.1	366.0	62.7	55.6	565.9	154.8	16.0	117.6
5/10/2013	19	1.5	3.7	21.2	240.0	38.2	33.0	376.7	101.5	10.6	71.2
5/10/2013	20										
5/10/2013	21										
5/10/2013	22										

Date	Plot #	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg m^{-2} $event^{-1}$					
5/10/2013	23										
5/10/2013	24	1.4	2.5	12.4	199.0	18.9	15.0	232.7	77.2	6.0	39.3
6/2/2013	1	0.6	0.3	1.8	19.6	2.4	1.5	39.7	15.2	0.7	5.7
6/2/2013	2	4.9	2.2	10.5	137.1	16.9	9.8	215.2	51.0	3.1	17.1
6/2/2013	3	1.5	0.5	3.5	53.4	7.1	5.0	77.4	42.9	1.4	6.5
6/2/2013	4	1.2	1.4	6.2	104.1	8.5	5.9	135.2	35.0	2.1	13.2
6/2/2013	5	1.0	1.7	6.6	107.7	8.3	5.6	146.5	30.6	1.9	11.8
6/2/2013	6	1.6	1.5	4.2	62.0	6.8	3.7	80.1	24.6	1.2	8.6
6/2/2013	7	1.3	1.4	5.5	83.0	7.8	5.2	99.1	36.4	2.1	11.6
6/2/2013	8	0.5	1.1	6.0	76.5	5.9	4.2	96.3	32.8	1.8	10.4
6/2/2013	9	4.7	13.4	20.5	257.3	29.2	12.8	365.4	77.5	5.5	30.5
6/2/2013	10	0.7	0.9	6.1	64.1	4.7	3.0	98.2	25.7	1.5	9.3
6/2/2013	11	0.2	0.2	1.4	14.6	1.4	0.9	27.1	6.4	0.4	2.9
6/2/2013	12	0.7	1.6	7.8	73.4	6.0	3.7	138.7	43.1	2.2	13.9
6/2/2013	13	1.1	2.4	15.9	242.7	16.8	13.2	301.9	84.8	5.0	31.4
6/2/2013	14	1.8	5.8	19.4	331.6	23.4	15.7	774.3	105.6	8.0	51.8
6/2/2013	15	1.4	1.9	13.3	194.9	12.6	9.4	521.4	65.2	4.4	28.3
6/2/2013	16	1.2	1.8	13.8	127.7	9.4	6.4	222.1	70.3	3.4	21.2
6/2/2013	17	0.9	1.8	12.6	145.0	9.1	6.5	232.4	56.5	3.7	27.5
6/2/2013	18	1.6	3.0	23.8	274.0	19.2	14.6	434.2	100.5	6.4	37.8
6/2/2013	19	1.0	2.2	14.2	141.2	11.1	7.9	222.9	61.0	3.7	19.8
6/2/2013	20	1.4	2.5	9.9	92.9	9.5	5.6	169.7	44.2	2.2	18.7
6/2/2013	21	1.4	1.8	9.2	102.2	9.7	6.5	357.5	43.6	2.5	12.1
6/2/2013	22	0.3	0.5	2.5	33.8	3.2	2.4	51.3	15.3	1.0	5.4
6/2/2013	23	1.0	3.0	9.6	121.0	10.8	6.8	179.7	41.7	2.6	16.9
6/2/2013	24	0.5	4.6	6.6	88.5	10.4	5.3	115.4	33.3	2.0	9.6

Date	Plot #	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg m^{-2} $event^{-1}$					
8/13/2013	1	0.3	0.0	0.2	2.8	0.5	0.2	26.3	1.9	0.1	0.5
8/13/2013	2	1.4	0.5	3.7	71.8	8.3	6.4	794.6	38.9	2.9	15.7
8/13/2013	3	0.4	0.1	1.0	11.3	1.4	1.0	115.3	6.8	0.3	1.6
8/13/2013	4	0.7	0.2	1.1	20.6	2.6	1.7	212.4	9.2	0.9	3.5
8/13/2013	5	6.4	0.8	16.5	264.9	26.6	19.4	881.9	91.0	7.1	26.2
8/13/2013	6	1.7	0.3	3.6	72.9	8.2	6.2	343.7	28.4	1.8	8.3
8/13/2013	7	1.2	0.2	1.6	29.9	5.1	3.7	218.0	14.2	0.7	4.1
8/13/2013	8	0.1	0.1	1.0	12.2	1.0	0.8	65.7	7.0	0.4	1.8
8/13/2013	9	10.3	1.2	29.7	418.1	44.9	33.4	1532.8	171.9	11.4	50.1
8/13/2013	10	0.5	0.2	1.1	30.5	2.7	2.1	187.9	7.0	0.7	3.6
8/13/2013	11	0.1	0.0	0.2	3.2	0.4	0.3	16.7	1.7	0.1	0.7
8/13/2013	12	0.5	0.2	2.7	43.7	4.7	4.0	211.5	20.5	1.0	4.4
8/13/2013	13	0.4	0.3	1.7	29.3	2.4	1.7	375.0	11.6	1.6	6.2
8/13/2013	14	4.6	4.0	113.7	1546.6	111.9	103.4	4575.0	441.1	45.0	179.0
8/13/2013	15	10.3	3.7	65.7	1001.4	91.0	77.0	2741.1	343.2	26.3	109.3
8/13/2013	16	0.3	0.1	2.1	25.9	2.7	2.3	126.8	14.8	0.8	3.2
8/13/2013	17	1.3	0.7	10.3	217.6	15.8	13.9	783.6	100.3	6.0	24.1
8/13/2013	18	2.1	1.2	27.0	486.8	31.1	27.9	1635.6	155.5	12.1	56.3
8/13/2013	19	0.6	0.4	10.7	138.2	10.2	9.2	576.3	66.3	4.6	17.4
8/13/2013	20	0.7	0.3	6.1	66.0	5.7	4.8	287.9	35.9	2.2	8.7
8/13/2013	21	1.1	0.6	15.3	192.6	15.1	13.4	683.3	82.6	5.6	22.9
8/13/2013	22	0.7	0.1	1.8	19.5	2.3	1.5	100.0	12.2	0.7	2.7
8/13/2013	23	0.4	0.1	1.2	16.6	2.0	1.5	159.9	9.0	0.5	3.0
8/13/2013	24	0.3	0.1	1.5	23.4	2.7	2.2	112.5	8.3	0.5	2.2
9/20/2013	1	16.6	4.3	22.8	155.9	38.8	18.0	197.6	72.1	3.2	8.8
9/20/2013	2	18.4	5.1	79.4	578.4	67.0	43.5	648.8	190.2	10.6	28.6

Date	Plot #	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg m^{-2} $event^{-1}$					
9/20/2013	3	10.9	2.1	26.1	142.5	25.8	12.9	212.3	64.7	3.1	10.5
9/20/2013	4	11.8	2.7	34.0	247.6	32.3	17.8	296.0	102.8	5.5	14.9
9/20/2013	5	30.1	9.7	85.7	788.2	94.3	54.5	780.0	228.1	10.8	36.3
9/20/2013	6	40.8	8.3	56.5	560.3	96.8	47.7	558.1	181.0	7.1	27.5
9/20/2013	7	6.0	2.3	20.1	113.2	17.0	8.6	378.4	110.6	5.0	22.1
9/20/2013	8	2.0	3.2	60.8	315.2	25.0	19.7	353.1	127.5	6.1	20.4
9/20/2013	9	48.1	12.1	214.8	1329.5	152.8	92.6	1616.1	452.1	26.0	83.4
9/20/2013	10	29.6	3.3	78.3	420.5	66.4	33.6	635.2	216.1	10.7	33.9
9/20/2013	11	13.4	1.6	33.3	178.1	30.7	15.7	228.7	78.5	4.7	13.0
9/20/2013	12	15.4	3.2	77.7	408.0	47.2	28.6	453.1	139.1	7.9	22.3
9/20/2013	13	14.2	3.9	87.7	491.4	50.1	32.0	536.7	174.6	10.3	28.5
9/20/2013	14	22.1	22.6	300.7	2089.6	202.5	157.8	1761.9	634.1	35.4	87.2
9/20/2013	15	62.4	16.7	209.4	1755.4	215.6	136.4	1677.6	539.4	25.9	93.3
9/20/2013	16	3.4	5.7	150.9	961.0	62.0	52.9	1052.0	334.5	18.6	61.1
9/20/2013	17	6.7	4.5	137.9	713.9	51.4	40.2	857.2	258.0	12.6	45.3
9/20/2013	18	8.8	9.7	218.0	1228.6	86.5	68.0	1424.6	421.4	20.8	76.7
9/20/2013	19	3.8	5.2	136.4	657.2	44.1	35.1	832.1	213.4	12.4	43.5
9/20/2013	20	20.9	5.3	87.7	415.6	60.2	34.0	538.2	170.7	17.6	46.8
9/20/2013	21	7.1	11.4	164.5	1039.1	82.5	64.0	1156.9	259.5	14.9	57.1
9/20/2013	22	11.6	2.1	36.7	194.9	31.0	17.3	238.8	98.0	5.4	13.5
9/20/2013	23	3.8	3.8	83.6	417.2	31.9	24.3	508.7	161.1	9.1	27.9
9/20/2013	24	26.5	5.7	107.4	598.6	77.2	45.0	704.3	269.4	12.4	36.9
9/30/2013	1	4.0	14.5	17.5	178.0	36.8	18.3	217.5	130.9	8.2	15.3
9/30/2013	2	8.9	1.7	19.0	164.5	20.3	9.8	240.4	71.4	3.1	12.1
9/30/2013	3										
9/30/2013	4	6.2	1.4	11.2	112.9	14.4	6.7	146.1	59.7	3.5	9.0

Date	Plot #	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg m^{-2} $event^{-1}$					
9/30/2013	5										
9/30/2013	6	18.3	5.8	19.2	233.3	40.9	16.7	322.5	160.7	9.3	21.1
9/30/2013	7	6.9	2.4	14.6	128.3	17.5	8.2	149.9	66.8	3.1	12.6
9/30/2013	8	0.9	1.3	21.0	132.8	9.0	6.7	171.2	67.6	4.0	11.7
9/30/2013	9	21.9	2.6	58.3	475.9	53.9	29.5	707.9	201.6	12.9	42.4
9/30/2013	10	18.8	1.9	46.3	352.3	42.9	22.1	464.2	159.5	9.2	30.2
9/30/2013	11	22.0	1.8	49.4	362.6	46.2	22.5	381.9	154.7	8.1	25.7
9/30/2013	12	11.7	1.8	55.2	421.8	37.3	23.8	507.0	181.5	12.7	32.9
9/30/2013	13	7.8	2.0	25.7	219.7	21.8	12.0	287.7	98.5	5.5	16.4
9/30/2013	14	17.6	7.3	125.3	1063.1	85.6	60.7	1452.1	366.3	24.0	92.5
9/30/2013	15	23.9	5.1	68.3	611.5	65.7	36.7	919.9	270.4	17.2	53.7
9/30/2013	16	2.5	3.4	68.9	611.0	36.6	30.6	744.2	224.9	15.8	46.8
9/30/2013	17	3.1	2.0	73.0	531.2	31.3	26.2	706.6	231.9	15.3	44.5
9/30/2013	18	5.4	3.0	87.0	620.0	38.3	29.9	905.8	224.6	18.4	53.6
9/30/2013	19	2.7	2.0	64.2	430.6	25.6	20.9	549.2	174.5	12.4	36.7
9/30/2013	20	5.6	1.5	32.7	202.0	19.2	12.1	275.0	112.9	5.4	17.4
9/30/2013	21	3.2	14.0	55.0	435.1	42.8	25.5	597.9	170.5	10.3	35.8
9/30/2013	22	6.8	2.0	26.6	260.8	24.7	15.9	266.6	114.7	5.1	18.5
9/30/2013	23	1.8	1.2	27.7	178.7	12.1	9.1	221.0	76.8	3.3	13.0
9/30/2013	24	16.8	3.7	43.6	329.6	40.7	20.3	490.0	211.4	10.1	33.3
10/13/2013	1	70.8	23.3	113.3	719.0	157.4	63.3	1098.2	529.6	33.9	85.7
10/13/2013	2	178.6	18.5	113.7	836.1	260.8	63.7	2006.7	730.9	38.2	88.3
10/13/2013	3	53.3	6.5	42.7	265.9	77.7	17.9	560.4	253.9	13.3	32.4
10/13/2013	4	28.2	14.3	59.3	483.4	77.6	35.1	681.1	292.2	14.4	39.8
10/13/2013	5										
10/13/2013	6	67.3	9.5	35.1	265.8	99.0	22.2	542.7	235.5	10.6	27.6

Date	Plot #	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg m^{-2} $event^{-1}$					
10/13/2013	7	27.6	11.6	101.7	613.3	78.0	38.9	710.2	373.3	15.3	43.5
10/13/2013	8	8.3	5.7	57.2	461.8	38.9	24.9	572.4	228.7	12.2	37.1
10/13/2013	9	188.7	28.0	181.6	1087.8	296.0	79.3	2509.0	861.6	44.3	113.0
10/13/2013	10	146.9	22.1	127.3	801.8	228.5	59.4	1649.9	623.2	31.8	78.3
10/13/2013	11	97.4	24.6	122.3	1107.1	194.5	72.5	1552.5	622.7	30.0	81.1
10/13/2013	12	108.9	26.9	168.6	1346.8	218.9	83.0	2029.1	788.2	36.8	102.8
10/13/2013	13	121.7	19.7	148.7	969.2	206.3	64.9	1738.5	676.8	34.8	88.1
10/13/2013	14	78.0	23.7	149.0	1039.1	164.6	62.9	1974.2	529.3	32.3	86.8
10/13/2013	15	101.8	24.6	134.5	946.8	191.6	65.1	1883.2	568.4	30.6	86.1
10/13/2013	16	27.8	15.3	118.0	928.6	100.6	57.6	1206.7	440.6	22.6	72.3
10/13/2013	17	20.5	13.2	117.9	763.2	79.2	45.5	1063.9	437.3	18.8	56.6
10/13/2013	18	25.1	8.0	74.6	470.1	57.7	24.6	817.4	241.7	11.5	38.1
10/13/2013	19	14.2	8.0	83.1	483.7	47.1	24.9	825.4	264.0	15.1	43.3
10/13/2013	20	47.9	8.0	83.4	444.7	85.6	29.7	974.6	377.4	24.0	56.1
10/13/2013	21	13.3	6.1	67.8	390.3	43.1	23.6	670.9	212.6	13.4	38.5
10/13/2013	22	41.7	12.7	93.1	562.0	91.3	36.9	985.7	453.1	23.8	60.4
10/13/2013	23	19.3	9.7	94.6	567.0	61.1	32.2	860.9	328.8	17.5	50.6
10/13/2013	24	64.3	11.8	72.8	397.2	101.3	25.3	915.8	342.4	19.6	49.4
5/9/2014	1	87.7	9.0	24.4	333.4	101.7	4.9	770.9	254.9	188.4	1317.3
5/9/2014	2	62.2	5.8	25.2	385.4	78.1	10.0	1067.3	238.2	181.7	1375.1
5/9/2014	3	33.7	2.8	11.7	171.8	40.0	3.4	428.7	135.4	107.4	801.6
5/9/2014	4	17.6	2.0	8.6	148.0	24.0	4.4	378.1	93.7	74.8	796.5
5/9/2014	5	25.9	4.8	16.3	402.9	45.2	14.4	1280.0	252.1	165.8	1775.9
5/9/2014	6	33.5	4.8	17.1	330.7	48.9	10.8	950.1	215.4	151.4	1645.8
5/9/2014	7	38.9	3.4	16.0	182.4	45.5	3.1	475.6	171.1	107.2	832.5
5/9/2014	8	16.2	3.0	16.8	200.0	28.0	8.8	528.0	140.8	88.3	724.5

Date	Plot #	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg m^{-2} $event^{-1}$					
5/9/2014	9	76.1	4.6	23.9	900.5	85.6	11.8	2722.2	327.1	204.5	2153.8
5/9/2014	10	28.8	3.2	15.6	247.9	40.1	8.1	774.1	156.8	129.6	1419.7
5/9/2014	11	18.9	1.2	6.6	93.6	21.5	1.3	253.6	69.1	49.5	455.7
5/9/2014	12	28.2	2.5	13.0	177.5	33.8	3.2	484.0	122.7	94.4	893.1
5/9/2014	13	22.0	2.4	13.0	193.1	29.4	6.0	520.9	127.7	98.0	898.6
5/9/2014	14	37.4	5.0	25.0	637.2	57.4	15.1	1858.4	260.6	186.3	2207.5
5/9/2014	15	21.2	6.0	16.8	490.1	43.4	16.1	1535.1	226.0	141.0	1548.5
5/9/2014	16	16.3	2.7	25.4	334.0	32.7	13.7	882.3	242.6	112.1	955.7
5/9/2014	17	16.9	2.7	16.0	211.4	27.6	7.9	593.2	154.0	97.6	772.4
5/9/2014	18	36.9	4.5	29.2	482.4	58.2	16.8	1497.0	286.9	201.8	1837.1
5/9/2014	19	21.0	2.9	19.9	261.6	33.2	9.2	747.1	185.0	134.7	1133.7
5/9/2014	20	24.6	3.1	17.0	224.3	35.2	7.5	607.4	147.3	100.1	976.0
5/9/2014	21	13.8	3.0	15.0	207.2	24.7	7.9	601.1	125.7	87.8	862.9
5/9/2014	22	30.1	3.2	16.3	199.8	39.3	6.1	504.7	149.6	97.4	861.4
5/9/2014	23	2.2	0.5	1.6	22.8	3.6	0.9	60.1	15.5	9.4	84.1
5/9/2014	24	34.5	5.3	20.4	357.6	53.0	13.2	842.8	190.4	112.8	1014.9
5/13/2014	1	141.8	14.7	73.2	1062.4	197.5	41.0	1508.4	665.0	420.2	4190.9
5/13/2014	2	67.4	9.2	54.7	838.1	105.4	28.9	1461.4	450.0	402.8	4578.8
5/13/2014	3	54.2	7.1	44.4	645.9	80.6	19.3	1012.8	483.0	436.7	4888.3
5/13/2014	4	36.3	7.3	42.9	679.4	68.7	25.1	1092.3	369.1	323.9	4405.5
5/13/2014	5	29.8	13.1	69.6	1230.9	85.4	42.5	3107.9	643.8	498.0	6575.8
5/13/2014	6	45.8	8.5	59.5	780.7	84.2	30.0	1523.8	463.7	304.2	3910.0
5/13/2014	7	51.3	6.9	73.7	588.7	79.0	20.8	894.7	477.1	359.9	4242.5
5/13/2014	8	40.8	9.4	115.9	1028.8	90.8	40.6	1568.5	536.2	313.5	3449.3
5/13/2014	9	45.3	9.9	66.4	1129.7	99.3	44.1	2027.7	402.1	221.3	2770.4
5/13/2014	10	64.4	9.3	89.8	1075.9	119.1	45.5	2195.1	629.0	502.1	7028.6

Date	Plot #	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg m^{-2} $event^{-1}$					
5/13/2014	11	65.0	8.3	76.3	805.5	107.5	34.1	1449.1	573.2	503.2	6532.2
5/13/2014	12										
5/13/2014	13	26.2	7.9	52.5	707.0	63.1	29.0	1326.1	433.4	327.7	3975.9
5/13/2014	14	41.3	11.7	95.8	1368.9	109.4	56.4	2904.8	599.3	395.3	5743.9
5/13/2014	15	22.9	7.5	56.2	902.7	64.4	34.0	1635.0	378.6	227.2	3175.5
5/13/2014	16	20.9	8.1	77.2	1112.5	74.0	45.0	1897.1	592.8	301.3	3019.1
5/13/2014	17	26.2	9.0	79.2	841.1	66.8	31.6	1586.5	534.8	408.5	4602.7
5/13/2014	18	40.9	10.1	81.5	876.7	93.9	43.0	2071.0	536.5	398.1	4947.6
5/13/2014	19	19.8	7.2	63.6	646.0	58.5	31.5	1433.4	414.4	344.1	4149.4
5/13/2014	20	26.9	5.9	58.4	549.4	58.7	25.9	1070.0	354.4	304.8	4190.1
5/13/2014	21	14.2	5.8	49.3	486.8	39.3	19.3	1060.4	333.7	223.3	2867.1
5/13/2014	22	54.4	8.7	81.5	624.8	81.6	21.3	1422.1	620.6	482.4	6369.6
5/13/2014	23	20.8	6.4	56.4	411.8	38.1	16.0	1072.1	357.0	285.9	3591.1
5/13/2014	24	37.2	7.6	59.0	696.2	83.3	38.5	1339.8	411.4	267.6	3216.4
5/27/2014	1	46.7	5.1	10.9	178.1	86.6	34.8	165.1	88.9	34.4	321.3
5/27/2014	2	21.5	3.2	5.6	109.8	56.3	31.6	96.5	37.8	14.4	148.8
5/27/2014	3	17.9	1.9	5.1	86.9	41.9	22.0	84.2	48.6	20.8	201.8
5/27/2014	4	10.4	1.7	3.4	70.3	31.0	18.9	71.3	33.0	11.6	128.3
5/27/2014	5	5.7	1.4	7.1	156.0	33.2	26.1	265.4	52.5	28.6	296.1
5/27/2014	6	10.3	1.5	3.1	66.1	29.0	17.2	73.3	28.9	8.7	105.5
5/27/2014	7	20.4	3.2	7.0	101.0	51.0	27.4	95.5	59.0	21.3	236.9
5/27/2014	8	6.3	2.1	10.5	133.8	16.7	8.3	162.3	44.7	16.3	165.4
5/27/2014	9	28.3	4.3	7.4	123.8	63.1	30.6	161.6	51.6	13.8	154.0
5/27/2014	10	34.4	4.5	9.7	161.4	78.7	39.8	204.5	83.5	32.1	416.8
5/27/2014	11	25.1	3.4	7.5	126.1	61.7	33.2	127.3	72.4	35.9	450.2
5/27/2014	12	21.3	3.2	6.9	111.1	58.1	33.6	119.6	62.0	24.2	338.0

Date	Plot #	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg m^{-2} $event^{-1}$					
5/27/2014	13	7.2	1.5	3.3	59.0	26.2	17.5	62.9	32.0	9.5	115.9
5/27/2014	14	6.1	1.9	9.9	144.7	15.2	7.3	212.4	47.0	15.9	210.8
5/27/2014	15	17.6	3.4	6.6	124.1	53.1	32.0	161.4	66.0	16.2	189.6
5/27/2014	16	2.9	0.8	8.5	91.9	8.0	4.3	107.7	43.6	12.0	124.0
5/27/2014	17	23.0	5.1	12.7	185.1	77.5	49.4	204.6	97.9	31.4	340.5
5/27/2014	18	19.8	4.4	10.3	156.1	62.8	38.5	161.1	63.0	19.8	234.2
5/27/2014	19	13.9	3.8	8.6	129.3	58.3	40.6	150.2	78.8	18.5	218.4
5/27/2014	20	10.1	1.9	4.9	78.8	32.9	20.8	81.1	38.2	10.5	131.9
5/27/2014	21	2.4	0.6	4.2	51.6	5.5	2.5	73.5	22.1	8.2	95.0
5/27/2014	22	22.4	3.3	8.6	140.8	63.1	37.4	123.8	76.4	19.3	250.0
5/27/2014	23	4.7	1.0	6.3	74.1	8.8	3.1	84.9	29.3	11.6	132.5
5/27/2014	24	18.6	3.0	5.4	85.2	41.6	21.2	90.3	43.9	12.1	125.2
5/28/2014	1	22.9	3.8	19.4	367.8	58.4	31.7	239.1	117.6	48.5	438.8
5/28/2014	2	9.7	2.1	10.1	223.4	33.8	22.0	141.0	53.6	19.0	204.0
5/28/2014	3	12.0	1.9	10.2	202.7	33.5	19.5	134.3	73.7	31.9	338.4
5/28/2014	4	9.2	2.0	8.8	208.0	34.1	22.8	148.8	66.9	31.0	331.1
5/28/2014	5	3.8	2.4	14.4	346.8	17.2	11.1	309.6	66.5	39.7	459.9
5/28/2014	6	9.8	1.8	9.4	224.1	32.4	20.8	152.1	60.5	18.4	220.6
5/28/2014	7	13.5	2.4	12.7	198.7	37.0	21.1	165.9	105.9	42.7	400.1
5/28/2014	8	4.2	2.7	22.3	326.1	20.5	13.7	279.1	89.6	45.0	377.7
5/28/2014	9	14.0	2.4	16.3	267.9	41.7	25.3	259.0	77.9	18.2	190.6
5/28/2014	10	15.0	6.8	20.9	370.9	63.1	41.3	405.3	141.0	68.1	779.2
5/28/2014	11	14.1	3.1	16.7	283.5	50.8	33.7	255.1	137.0	73.3	925.3
5/28/2014	12	13.1	3.1	15.1	282.0	49.2	32.9	217.7	91.2	40.8	564.5
5/28/2014	13	6.6	1.6	8.6	163.1	28.4	20.3	127.9	59.8	24.3	274.6
5/28/2014	14	5.5	2.8	19.3	304.3	18.3	10.0	299.6	69.4	32.7	376.1

Date	Plot #	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg m^{-2} $event^{-1}$					
5/28/2014	15	11.5	2.7	14.4	273.0	40.4	26.3	225.0	97.0	30.7	342.2
5/28/2014	16	3.0	1.9	22.0	290.4	15.7	10.8	224.0	84.7	32.2	314.3
5/28/2014	17	11.3	3.2	20.3	305.9	46.7	32.2	249.2	119.9	47.9	492.4
5/28/2014	18	14.9	3.0	20.5	307.9	50.1	32.1	288.1	117.3	45.1	485.0
5/28/2014	19	8.5	2.4	16.7	249.8	36.6	25.6	164.5	77.9	29.3	325.8
5/28/2014	20	9.1	2.2	12.6	215.9	33.0	21.8	156.8	73.3	28.8	304.9
5/28/2014	21	3.0	1.4	11.7	166.5	10.1	5.7	105.3	36.5	17.7	209.6
5/28/2014	22	15.2	3.5	17.8	309.7	51.7	33.0	204.3	124.6	50.4	567.1
5/28/2014	23	4.3	2.6	15.9	218.2	13.8	6.9	172.4	62.4	32.0	325.6
5/28/2014	24	13.7	2.5	13.8	244.2	41.0	24.8	152.0	74.8	24.1	233.6
6/24/2014	1										
6/24/2014	2										
6/24/2014	3										
6/24/2014	4	0.0	0.0	0.1	3.8	0.1	0.1	10.6	0.3	0.0	0.3
6/24/2014	5										
6/24/2014	6										
6/24/2014	7										
6/24/2014	8										
6/24/2014	9										
6/24/2014	10										
6/24/2014	11										
6/24/2014	12										
6/24/2014	13	0.6	0.1	0.5	30.1	1.0	0.3	85.8	3.7	0.8	7.7
6/24/2014	14	1.0	0.9	10.1	274.4	15.2	13.4	313.1	49.9	3.1	35.1
6/24/2014	15	2.9	2.8	25.3	714.0	42.6	36.8	951.8	149.1	8.6	107.2
6/24/2014	16										

Date	Plot #	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg m^{-2} $event^{-1}$					
6/24/2014	17										
6/24/2014	18	0.5	0.6	11.9	192.3	9.4	8.3	313.9	64.3	3.4	39.2
6/24/2014	19										
6/24/2014	20										
6/24/2014	21										
6/24/2014	22										
6/24/2014	23										
6/24/2014	24										
7/5/2014	1										
7/5/2014	2	0.0	0.1	0.2	7.8	0.4	0.3	12.9	1.7	0.2	1.6
7/5/2014	3										
7/5/2014	4										
7/5/2014	5	0.0	0.0	0.2	9.8	0.3	0.3	15.7	2.3	0.2	2.1
7/5/2014	6										
7/5/2014	7										
7/5/2014	8										
7/5/2014	9										
7/5/2014	10										
7/5/2014	11										
7/5/2014	12										
7/5/2014	13										
7/5/2014	14	0.0	0.0	0.2	6.6	0.2	0.2	12.0	1.4	0.2	1.4
7/5/2014	15	4.6	16.3	5.0	312.3	44.2	23.3	525.7	86.7	7.4	69.2
7/5/2014	16										
7/5/2014	17										
7/5/2014	18	0.1	0.6	2.0	46.5	2.3	1.5	79.7	11.8	1.1	10.2

Date	Plot #	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg m^{-2} $event^{-1}$					
7/5/2014	19										
7/5/2014	20										
7/5/2014	21										
7/5/2014	22										
7/5/2014	23										
7/5/2014	24										
7/7/2014	1										
7/7/2014	2										
7/7/2014	3										
7/7/2014	4										
7/7/2014	5										
7/7/2014	6										
7/7/2014	7										
7/7/2014	8										
7/7/2014	9										
7/7/2014	10										
7/7/2014	11										
7/7/2014	12										
7/7/2014	13										
7/7/2014	14										
7/7/2014	15										
7/7/2014	16										
7/7/2014	17										
7/7/2014	18										
7/7/2014	19										
7/7/2014	20										

Date	Plot #	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg m^{-2} $event^{-1}$					
7/7/2014	21	0.0	0.0	0.1	2.1	0.1	0.1	3.5	0.5	0.0	0.4
7/7/2014	22										
7/7/2014	23										
7/7/2014	24										
7/18/2014	1	96.4	30.0	150.0	1714.0	206.2	82.8	1864.9	1022.4	28.7	157.2
7/18/2014	2	59.4	47.1	248.0	3060.9	354.7	248.2	3300.6	1330.8	40.7	274.3
7/18/2014	3	65.8	34.2	188.2	2441.2	310.7	210.7	2130.9	1377.4	45.6	511.4
7/18/2014	4	101.9	69.2	442.5	6114.0	694.6	523.4	5259.4	2666.9	70.0	408.9
7/18/2014	5	78.8	57.3	415.8	4404.3	455.6	319.4	5555.6	2116.9	66.9	401.4
7/18/2014	6	113.5	61.7	332.4	6414.2	728.9	553.8	4938.1	2499.1	62.0	411.1
7/18/2014	7	53.0	34.7	252.7	3028.0	344.0	256.3	2658.1	1632.0	35.6	189.1
7/18/2014	8	38.6	36.0	310.8	3662.8	396.7	322.2	3263.6	1482.5	53.1	340.1
7/18/2014	9	196.5	92.4	669.1	10006.6	1131.1	842.2	11226.6	3347.9	106.8	676.6
7/18/2014	10	130.0	72.4	448.0	4517.7	587.2	386.6	6638.2	2764.0	82.1	526.6
7/18/2014	11	216.4	87.6	458.0	6034.5	672.8	368.8	5673.5	3042.8	92.7	566.5
7/18/2014	12	34.9	17.6	130.0	1314.6	150.2	97.7	1501.9	723.7	21.5	124.1
7/18/2014	13	53.4	38.2	365.5	3781.5	422.6	331.0	4905.5	2007.8	63.0	651.6
7/18/2014	14	78.4	57.9	573.5	5672.6	520.2	383.9	5600.4	1972.6	51.6	369.2
7/18/2014	15										
7/18/2014	16	108.1	65.5	716.1	6169.8	640.8	467.2	7107.5	3473.2	144.2	927.2
7/18/2014	17	85.8	52.8	473.8	4486.3	509.8	371.2	5087.1	2443.0	75.2	534.8
7/18/2014	18	53.6	31.7	328.9	2531.8	263.3	178.0	3742.4	1314.9	48.8	346.2
7/18/2014	19	51.7	34.2	286.1	2808.4	304.6	218.6	3114.3	1639.7	43.7	291.9
7/18/2014	20	39.5	30.5	216.2	3204.8	371.4	301.4	2815.5	1267.4	39.6	287.5
7/18/2014	21	21.6	18.6	169.0	1173.6	118.7	78.5	1877.9	796.7	27.3	322.1
7/18/2014	22	40.3	27.2	183.8	2893.8	327.4	259.9	2182.8	1258.3	31.5	204.9

Date	Plot #	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg m^{-2} $event^{-1}$					
7/18/2014	23	20.1	16.2	162.5	1243.1	123.4	87.2	1698.4	819.6	21.0	134.2
7/18/2014	24	24.6	17.0	114.1	1768.8	200.9	159.3	1372.1	648.3	17.3	105.2
9/15/2014	1	25.4	25.1	123.0	650.3	97.2	46.7	737.9	355.9	7.0	32.4
9/15/2014	2	8.7	12.4	104.8	508.3	53.4	32.4	653.8	179.6	4.5	22.3
9/15/2014	3	6.4	6.8	37.5	260.0	30.1	16.9	351.1	141.9	3.1	15.3
9/15/2014	4	11.0	13.7	131.3	450.1	56.0	31.4	539.6	203.2	3.5	23.2
9/15/2014	5	18.1	31.9	175.6	1572.9	139.7	89.8	2127.6	570.0	9.6	91.7
9/15/2014	6	30.1	30.7	115.1	1860.8	171.0	110.2	3793.6	532.4	33.2	174.2
9/15/2014	7	18.0	39.5	91.8	809.5	130.9	73.4	666.7	243.5	5.4	39.5
9/15/2014	8	8.0	18.1	186.2	764.5	72.0	46.0	938.8	261.3	7.1	39.2
9/15/2014	9	18.5	23.0	102.1	989.5	105.4	63.8	1137.5	294.4	5.3	42.7
9/15/2014	10	18.6	16.1	138.3	702.7	83.3	48.7	829.0	253.6	5.3	30.2
9/15/2014	11	38.9	16.1	84.1	643.4	104.5	49.5	782.6	294.4	6.3	41.9
9/15/2014	12	34.0	20.1	132.5	732.1	104.9	50.8	913.9	366.8	6.4	46.3
9/15/2014	13	8.8	13.4	134.6	542.9	55.6	33.4	973.9	252.3	5.9	37.5
9/15/2014	14	13.0	29.7	138.5	1331.0	124.3	81.6	1755.0	400.4	14.2	77.6
9/15/2014	15	17.2	21.3	205.9	1112.5	109.7	71.2	1612.3	348.9	8.2	57.6
9/15/2014	16	19.8	23.7	200.3	1487.8	130.2	86.7	1366.2	418.9	11.6	68.8
9/15/2014	17	24.4	19.8	226.2	987.4	110.4	66.3	1031.7	377.9	9.4	50.1
9/15/2014	18	16.4	24.3	217.9	1396.9	123.3	82.5	1913.9	428.0	9.3	74.6
9/15/2014	19	14.1	20.1	152.6	940.2	92.7	58.5	1090.7	311.6	4.7	49.7
9/15/2014	20	10.0	10.5	124.7	597.1	59.9	39.5	849.3	258.1	3.4	35.8
9/15/2014	21	8.1	13.8	141.1	707.4	63.2	41.3	789.0	187.2	7.5	32.4
9/15/2014	22	20.5	25.5	189.8	1053.3	117.6	71.6	1171.5	435.8	10.1	54.7
9/15/2014	23	5.5	8.0	104.7	358.8	32.9	19.4	524.6	160.8	3.0	20.0
9/15/2014	24	9.6	10.8	114.0	506.9	50.6	30.2	765.6	194.8	5.6	33.5

Date	Plot #	NO_3-N	NH_4-N	PO_4-P	DOC	TDN	DON	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg m^{-2} $event^{-1}$					
10/13/2014	1										
10/13/2014	2										
10/13/2014	3										
10/13/2014	4										
10/13/2014	5										
10/13/2014	6										
10/13/2014	7										
10/13/2014	8										
10/13/2014	9										
10/13/2014	10	1.9	0.7	6.2	57.0	6.8	4.2	70.5	22.2	1.3	6.2
10/13/2014	11										
10/13/2014	12										
10/13/2014	13	0.4	0.4	2.3	40.2	3.0	2.1	43.9	12.5	0.6	3.4
10/13/2014	14	0.3	0.2	2.7	29.4	2.0	1.5	43.8	9.7	0.5	2.8
10/13/2014	15	1.9	0.8	7.1	101.5	9.4	6.6	148.7	40.0	1.8	10.9
10/13/2014	16	1.4	1.0	23.3	188.4	12.4	10.0	165.7	63.0	1.3	14.7
10/13/2014	17	0.7	0.5	7.1	66.1	4.8	3.5	107.8	26.3	1.3	7.5
10/13/2014	18	0.5	0.4	7.8	50.8	3.4	2.5	61.2	28.9	0.4	5.1
10/13/2014	19										
10/13/2014	20										
10/13/2014	21	0.4	0.3	1.6	33.5	2.8	2.1	37.6	11.8	0.7	3.7

APPENDIX C

MEAN RUNOFF CHEMISTRY DATA FOR SAMPLES COLLECTED BETWEEN JUNE 2015 AND OCTOBER 2015

Date	Plot #	%ET	FERT	WA	H_2O Source	pH	EC us cm_{-1}	NO_3-N	NH_4-N mg L^{-1}	PO_4-P	Runoff L
6/17/2015	1	30	0	1	Rain						0
6/17/2015	2	30	1	1	Rain	7.10	178.70	0.34	0.26	2.21	361.32
6/17/2015	3	30	0	0	Rain						0.36
6/17/2015	4	60	0	0	Rain	6.56	166.98	0.17	0.30	2.48	579.72
6/17/2015	5	30	0	1	Rain	6.58	178.37	0.13	0.18	2.93	321.36
6/17/2015	6	30	1	0	Rain	6.76	187.98	0.31	0.54	2.29	324.12
6/17/2015	7	30	0	0	Rain	7.21	193.60	0.14	0.93	3.14	305.64
6/17/2015	8	30	0	0	Rain	7.14	226.00	0.15	0.16	3.88	366.12
6/17/2015	9	30	0	0	Rain	6.88	203.50	0.13	0.26	3.39	603.12
6/17/2015	11	30	1	0	Rain	6.44	184.68	0.23	0.62	2.72	760.2
6/17/2015	12	30	1	1	Rain	6.37	199.72	0.21	1.17	3.30	659.28
6/17/2015	13	30	0	1	Rain	6.58	316.00	0.27	0.52	3.98	520.56
6/17/2015	14	60	0	0	Rain	7.08	240.88	0.15	1.07	3.71	874.32
6/17/2015	16	30	1	0	Rain	6.36	235.56	0.28	0.36	3.25	961.56
6/17/2015	17	30	1	1	Rain	6.51	207.06	0.17	0.58	3.15	884.76
6/17/2015	19	60	0	0	Rain	5.87	246.32	0.11	0.31	3.60	768.24
6/17/2015	20	30	1	0	Rain	6.48	217.32	0.14	0.33	2.55	708
6/17/2015	21	60	0	0	Rain	6.96	248.74	0.13	0.48	4.28	784.8
6/17/2015	22	30	1	1	Rain	7.52	189.80	0.41	0.27	2.34	946.08
6/17/2015	23	30	0	1	Rain						0

Date	Plot #	%ET	FERT	WA	H_2O Source	pH	EC us cm_{-1}	NO_3-N	NH_4-N mg L^{-1}	PO_4-P	Runoff L
6/19/2015	1	30	0	1	Rain						0
6/19/2015	2	30	1	1	Rain						0
6/19/2015	3	30	0	0	Rain						0
6/19/2015	4	60	0	0	Rain	7.25	276.50	0.43	3.15	2.38	44.88
6/19/2015	5	30	0	1	Rain						0
6/19/2015	6	30	1	0	Rain						0
6/19/2015	7	30	0	0	Rain						10.8
6/19/2015	8	30	0	0	Rain						0.12
6/19/2015	9	30	0	0	Rain	7.22	470.10	0.15	10.13	6.13	97.56
6/19/2015	11	30	1	0	Rain	7.15	478.40	0.13	19.82	3.84	125.04
6/19/2015	12	30	1	1	Rain	7.23	461.20	0.19	17.92	3.74	141
6/19/2015	13	30	0	1	Rain						46.56
6/19/2015	14	60	0	0	Rain	7.14	400.25	0.13	1.83	3.29	98.04
6/19/2015	16	30	1	0	Rain	7.10	360.75	0.14	0.13	2.21	92.52
6/19/2015	17	30	1	1	Rain	7.09	329.13	0.12	0.30	2.49	156.24
6/19/2015	19	60	0	0	Rain						44.64
6/19/2015	20	30	1	0	Rain						55.92
6/19/2015	21	60	0	0	Rain	7.25	443.70	0.24	1.00	8.38	53.16
6/19/2015	22	30	1	1	Rain	7.17	345.40	0.16	1.09	2.30	126.36
6/19/2015	23	30	0	1	Rain	7.16	396.20	0.15	4.77	4.17	96.96
8/12/2015	1	30	0	1	Tap	8.92	1668.33	3.08	0.31	3.49	18.9
8/12/2015	2	30	1	1	Tap						0
8/12/2015	3	30	0	0	Tap	8.31	1565.00	1.67	1.02	9.97	18.9
8/12/2015	4	60	0	0	Tap	8.38	1201.40	0.81	0.14	3.45	140.04
8/12/2015	5	30	0	1	Tap	8.79	1425.00	2.17	0.45	5.00	18.9
8/12/2015	6	30	1	0	Tap	8.69	1490.00	0.93	0.59	7.46	0.12

Date	Plot #	%ET	FERT	WA	H_2O Source	pH	EC us cm_{-1}	NO_3-N	NH_4-N mg L^{-1}	PO_4-P	Runoff L
8/12/2015	7	30	0	0	Tap	8.62	1210.00	0.59	0.65	2.18	18.9
8/12/2015	8	30	0	0	Tap	8.72	1120.00	0.30	0.12	0.82	4.68
8/12/2015	9	30	0	0	Tap	8.32	1307.67	1.28	0.22	5.84	49.32
8/12/2015	11	30	1	0	Tap	8.30	1122.40	0.58	0.14	2.47	81.965
8/12/2015	12	30	1	1	Tap	8.62	1194.67	0.52	0.32	2.14	10.44
8/12/2015	13	30	0	1	Tap	8.62	1135.25	0.44	0.11	1.65	50.894
8/12/2015	14	60	0	0	Tap	8.28	1215.33	0.29	0.09	4.25	526.322
8/12/2015	16	30	1	0	Tap	8.14	1442.20	3.21	0.41	9.13	353.04
8/12/2015	17	30	1	1	Tap	8.35	1213.00	0.37	0.09	3.55	251.042
8/12/2015	19	60	0	0	Tap	8.39	1231.40	0.21	0.07	3.99	374.89
8/12/2015	20	30	1	0	Tap	8.44	1261.20	0.45	0.10	3.72	190.092
8/12/2015	21	60	0	0	Tap	8.36	1266.80	0.24	0.12	5.44	351.12
8/12/2015	22	30	1	1	Tap	8.41	1257.80	0.96	0.20	4.76	112.08
8/12/2015	23	30	0	1	Tap	8.41	1286.67	0.74	0.22	6.28	43.56
9/23/2015	1	30	0	1	Tap						0.00
9/23/2015	2	30	1	1	Tap	8.36	2281.00	4.75	3.57	15.88	0.00
9/23/2015	3	30	0	0	Tap	8.13	1333.50	2.12	0.49	6.24	0.00
9/23/2015	4	60	0	0	Tap	8.32	1140.60	1.32	0.27	4.38	85.56
9/23/2015	5	30	0	1	Tap	8.48	1100.00	1.05	0.39	2.73	0.00
9/23/2015	6	30	1	0	Tap						0.00
9/23/2015	7	30	0	0	Tap						0.00
9/23/2015	8	30	0	0	Tap	8.60	1111.50	0.73	0.35	2.97	18.90
9/23/2015	9	30	0	0	Tap	8.18	1451.50	4.09	0.72	7.95	6.12
9/23/2015	11	30	1	0	Tap	7.99	1171.00	1.32	0.35	4.75	63.12
9/23/2015	12	30	1	1	Tap	8.19	1138.00	0.90	0.31	3.01	8.16
9/23/2015	13	30	0	1	Tap	8.42	1128.33	0.83	0.19	2.54	24.24

Date	Plot #	%ET	FERT	WA	H_2O Source	pH	EC us cm_{-1}	NO_3-N	NH_4-N mg L^{-1}	PO_4-P	Runoff L
9/23/2015	14	60	0	0	Tap	8.13	1264.60	0.75	0.34	6.75	412.32
9/23/2015	16	30	1	0	Tap	7.85	1286.50	0.80	0.26	8.11	286.56
9/23/2015	17	30	1	1	Tap	8.03	1259.80	0.54	0.23	7.39	221.64
9/23/2015	19	60	0	0	Tap	8.24	1211.80	0.47	0.22	6.83	265.80
9/23/2015	20	30	1	0	Tap	8.40	1012.99	0.97	0.27	5.74	107.76
9/23/2015	21	60	0	0	Tap	8.15	1227.40	0.61	0.26	6.49	243.00
9/23/2015	22	30	1	1	Tap	8.20	1062.00	0.53	0.18	1.60	8.28
9/23/2015	23	30	0	1	Tap	8.24	1178.33	0.77	0.36	5.63	19.20
10/20/2015	1	30	0	1	Tap						0
10/20/2015	2	30	1	1	Tap	8.96	1557.50	2.52	0.66	8.98	18.9
10/20/2015	3	30	0	0	Tap	9.02	1407.50	2.44	0.31	5.46	18.9
10/20/2015	4	60	0	0	Tap	8.53	1231.00	2.06	0.29	4.63	71.88
10/20/2015	5	30	0	1	Tap	8.91	1498.50	1.84	0.24	3.01	0.96
10/20/2015	6	30	1	0	Tap	9.20	1900.50	6.42	0.38	7.87	18.9
10/20/2015	7	30	0	0	Tap						0
10/20/2015	8	30	0	0	Tap	9.36	1976.00	6.71	0.41	16.77	18.9
10/20/2015	9	30	0	0	Tap	9.39	2022.00	8.05	0.35	13.59	14.88
10/20/2015	11	30	1	0	Tap	8.63	1494.00	5.78	0.33	7.29	55.32
10/20/2015	12	30	1	1	Tap	9.11	1535.50	2.46	0.27	5.33	5.52
10/20/2015	13	30	0	1	Tap	8.74	1334.00	1.81	0.24	4.40	28.44
10/20/2015	14	60	0	0	Tap	8.55	1354.00	2.31	0.24	6.62	130.08
10/20/2015	16	30	1	0	Tap	8.36	1259.33	0.89	0.29	8.57	499.44
10/20/2015	17	30	1	1	Tap	8.62	1352.00	1.06	0.23	6.05	139.08
10/20/2015	19	60	0	0	Tap	8.46	1361.20	1.59	0.24	7.74	164.24
10/20/2015	20	30	1	0	Tap	8.43	1276.00	1.32	0.26	6.01	113.76
10/20/2015	21	60	0	0	Tap	8.46	1279.60	0.95	0.26	5.92	148.44

Date	Plot #	%ET	FERT	WA	H_2O Source	pH	EC us cm_{-1}	NO_3-N	NH_4-N mg L^{-1}	PO_4-P	Runoff L
10/20/2015	22	30	1	1	Tap	8.70	992.33	1.61	0.22	4.01	40.44
10/20/2015	23	30	0	1	Tap	8.69	1381.00	1.87	0.31	7.79	25.2
10/26/2015	1	30	0	1	Rain	7.596	222.34	0.334	0.30	6.42	673
10/26/2015	2	30	1	1	Rain	7.618	206.98	0.302	0.28	5.55	610
10/26/2015	3	30	0	0	Rain						0
10/26/2015	4	60	0	0	Rain	7.794	478.54	0.726	0.67	11.26	2614
10/26/2015	5	30	0	1	Rain	7.668	280.14	0.234	0.26	8.82	764
10/26/2015	6	30	1	0	Rain	7.984	220.62	0.388	0.33	9.08	561
10/26/2015	7	30	0	0	Rain	7.746	246.56	0.466	0.57	9.84	1210
10/26/2015	8	30	0	0	Rain	7.676	261.18	0.17	0.25	9.75	1155
10/26/2015	9	30	0	0	Rain	7.838	451	1.032	0.61	11.20	2440
10/26/2015	11	30	1	0	Rain	7.504	458.44	1.366	0.77	11.00	2952
10/26/2015	12	30	1	1	Rain	7.59	327.22	0.51	0.40	9.44	1615
10/26/2015	13	30	0	1	Rain	7.588	329.94	0.296	0.36	10.56	2069
10/26/2015	14	60	0	0	Rain	7.814	593.52	0.372	0.69	11.97	3159
10/26/2015	16	30	1	0	Rain	8.095	695.85	0.35	0.56	13.80	4323
10/26/2015	17	30	1	1	Rain	7.83	606.46	0.316	0.66	13.01	3705
10/26/2015	19	60	0	0	Rain	7.928	621.16	0.182	0.53	13.07	3111
10/26/2015	20	30	1	0	Rain	7.836	660.58	0.434	1.39	14.04	4110
10/26/2015	21	60	0	0	Rain	8.05	636.88	0.302	0.84	14.16	3324
10/26/2015	22	30	1	1	Rain	7.94	488.44	0.678	0.57	13.65	4037
10/26/2015	23	30	0	1	Rain	7.8	430	0.506	0.57	14.00	2439

APPENDIX D

INORGANIC N AND P EXPORTS

Date	Plot #	%ET	FERT	WA	H_2O source	NO_3-N	NH_4-N mg m^{-2}	PO_4-P
6/17/2015	1	30	0	1	Rain	0.00	0.00	0.00
6/17/2015	2	30	1	1	Rain	8.75	6.75	57.53
6/17/2015	3	30	0	0	Rain	0.00	0.00	0.00
6/17/2015	4	60	0	0	Rain	4.04	0.47	3.92
6/17/2015	5	30	0	1	Rain	1.39	1.95	31.48
6/17/2015	6	30	1	0	Rain	6.00	10.63	44.88
6/17/2015	7	30	0	0	Rain	3.60	24.38	82.57
6/17/2015	8	30	0	0	Rain	4.10	4.49	109.14
6/17/2015	9	30	0	0	Rain	1.30	2.48	32.64
6/17/2015	11	30	1	0	Rain	5.26	14.07	61.55
6/17/2015	12	30	1	1	Rain	6.05	33.40	94.51
6/17/2015	13	30	0	1	Rain	5.62	10.86	83.72
6/17/2015	14	60	0	0	Rain	0.00	0.00	0.00
6/17/2015	16	30	1	0	Rain	2.68	3.48	31.11
6/17/2015	17	30	1	1	Rain	2.58	9.05	48.79
6/17/2015	19	60	0	0	Rain	0.00	0.00	0.00
6/17/2015	20	30	1	0	Rain	0.00	0.00	0.03
6/17/2015	21	60	0	0	Rain	1.17	4.40	38.94
6/17/2015	22	30	1	1	Rain	4.52	2.89	25.44
6/17/2015	23	30	0	1	Rain	0.00	0.00	0.00
6/19/2015	1	30	0	1	Rain	0.00	0.00	0.00
6/19/2015	2	30	1	1	Rain	0.00	0.00	0.00
6/19/2015	3	30	0	0	Rain	0.00	0.00	0.00
6/19/2015	4	60	0	0	Rain	0.68	4.98	3.76
6/19/2015	5	30	0	1	Rain	0.00	0.00	0.00
6/19/2015	6	30	1	0	Rain	0.00	0.00	0.00
6/19/2015	7	30	0	0	Rain	0.00	0.00	0.00
6/19/2015	8	30	0	0	Rain	0.00	0.00	0.00
6/19/2015	9	30	0	0	Rain	0.00	0.00	0.00
6/19/2015	11	30	1	0	Rain	0.48	73.71	14.27
6/19/2015	12	30	1	1	Rain	0.52	49.30	10.30
6/19/2015	13	30	0	1	Rain	0.00	0.00	0.00
6/19/2015	14	60	0	0	Rain	0.00	0.00	0.00
6/19/2015	16	30	1	0	Rain	0.00	0.00	0.00
6/19/2015	17	30	1	1	Rain	0.17	0.41	3.45

Date	Plot #	%ET	FERT	WA	H_2O source	NO_3-N	NH_4-N mg m^{-2}	PO_4-P
6/19/2015	19	60	0	0	Rain	0.00	0.00	0.00
6/19/2015	20	30	1	0	Rain	0.00	0.00	0.00
6/19/2015	21	60	0	0	Rain	0.08	0.32	2.69
6/19/2015	22	30	1	1	Rain	0.00	0.00	0.01
6/19/2015	23	30	0	1	Rain	0.43	13.85	12.11
8/12/2015	1	30	0	1	Tap	12.82	1.30	14.52
8/12/2015	2	30	1	1	Tap	0.00	0.00	0.00
8/12/2015	3	30	0	0	Tap	18.63	11.41	111.13
8/12/2015	4	60	0	0	Tap	8.47	1.49	36.00
8/12/2015	5	30	0	1	Tap	0.00	0.00	0.00
8/12/2015	6	30	1	0	Tap	0.29	0.18	2.32
8/12/2015	7	30	0	0	Tap	4.41	4.83	16.28
8/12/2015	8	30	0	0	Tap	1.01	0.39	2.73
8/12/2015	9	30	0	0	Tap	0.00	0.00	0.02
8/12/2015	11	30	1	0	Tap	1.40	0.34	6.02
8/12/2015	12	30	1	1	Tap	5.43	3.32	22.49
8/12/2015	13	30	0	1	Tap	2.51	0.62	9.32
8/12/2015	14	60	0	0	Tap	0.16	0.05	2.39
8/12/2015	16	30	1	0	Tap	1.81	0.23	5.13
8/12/2015	17	30	1	1	Tap	0.56	0.13	5.38
8/12/2015	19	60	0	0	Tap	0.27	0.09	5.17
8/12/2015	20	30	1	0	Tap	0.25	0.06	2.09
8/12/2015	21	60	0	0	Tap	0.13	0.07	3.06
8/12/2015	22	30	1	1	Tap	0.13	0.03	0.66
8/12/2015	23	30	0	1	Tap	1.09	0.32	9.21
9/23/2015	1	30	0	1	Tap	0.00	0.00	0.00
9/23/2015	2	30	1	1	Tap	58.25	43.78	23.30
9/23/2015	3	30	0	0	Tap	16.76	0.71	9.15
9/23/2015	4	60	0	0	Tap	9.56	0.39	6.43
9/23/2015	5	30	0	1	Tap	0.00	0.57	4.00
9/23/2015	6	30	1	0	Tap	0.00	0.00	0.00
9/23/2015	7	30	0	0	Tap	0.00	0.00	0.00
9/23/2015	8	30	0	0	Tap	0.18	0.51	4.35
9/23/2015	9	30	0	0	Tap	0.00	1.06	11.66
9/23/2015	11	30	1	0	Tap	2.48	0.51	6.97
9/23/2015	12	30	1	1	Tap	7.63	0.45	4.41
9/23/2015	13	30	0	1	Tap	2.66	0.28	3.73
9/23/2015	14	60	0	0	Tap	0.00	0.50	9.91

Date	Plot #	%ET	FERT	WA	H_2O source	NO_3-N	NH_4-N mg m^{-2}	PO_4-P
9/23/2015	16	30	1	0	Tap	0.00	0.38	11.89
9/23/2015	17	30	1	1	Tap	0.39	0.34	10.84
9/23/2015	19	60	0	0	Tap	0.27	0.33	10.03
9/23/2015	20	30	1	0	Tap	0.00	0.40	8.42
9/23/2015	21	60	0	0	Tap	0.00	0.38	9.52
9/23/2015	22	30	1	1	Tap	0.30	0.26	2.34
9/23/2015	23	30	0	1	Tap	0.14	0.52	8.26
10/20/2015	1	30	0	1	Tap	0.00	0.00	0.00
10/20/2015	2	30	1	1	Tap	1.42	0.37	5.05
10/20/2015	3	30	0	0	Tap	1.37	0.17	3.07
10/20/2015	4	60	0	0	Tap	4.41	0.62	9.89
10/20/2015	5	30	0	1	Tap	0.05	0.01	0.09
10/20/2015	6	30	1	0	Tap	3.61	0.21	4.43
10/20/2015	7	30	0	0	Tap	0.00	0.00	0.00
10/20/2015	8	30	0	0	Tap	3.77	0.23	9.43
10/20/2015	9	30	0	0	Tap	3.56	0.15	6.01
10/20/2015	11	30	1	0	Tap	9.52	0.54	11.99
10/20/2015	12	30	1	1	Tap	0.40	0.05	0.87
10/20/2015	13	30	0	1	Tap	1.53	0.20	3.72
10/20/2015	14	60	0	0	Tap	8.95	0.92	25.62
10/20/2015	16	30	1	0	Tap	13.27	4.27	127.37
10/20/2015	17	30	1	1	Tap	4.39	0.95	25.01
10/20/2015	19	60	0	0	Tap	7.76	1.15	37.80
10/20/2015	20	30	1	0	Tap	4.48	0.88	20.34
10/20/2015	21	60	0	0	Tap	4.21	1.16	26.12
10/20/2015	22	30	1	1	Tap	1.93	0.26	4.82
10/20/2015	23	30	0	1	Tap	1.40	0.23	5.84
10/26/2015	1	30	0	1	Rain	6.69	6.09	128.51
10/26/2015	2	30	1	1	Rain	5.48	5.04	100.77
10/26/2015	3	30	0	0	Rain	0.00	0.00	0.00
10/26/2015	4	60	0	0	Rain	56.45	51.90	875.67
10/26/2015	5	30	0	1	Rain	5.32	5.95	200.48
10/26/2015	6	30	1	0	Rain	6.47	5.47	151.58
10/26/2015	7	30	0	0	Rain	16.77	20.66	354.22
10/26/2015	8	30	0	0	Rain	5.84	8.66	335.03
10/26/2015	9	30	0	0	Rain	74.90	44.27	812.56
10/26/2015	11	30	1	0	Rain	119.94	67.61	965.68
10/26/2015	12	30	1	1	Rain	24.50	19.41	453.56

Date	Plot #	%ET	FERT	WA	H_2O source	NO_3-N	NH_4-N mg m^{-2}	PO_4-P
10/26/2015	13	30	0	1	Rain	18.22	22.03	650.12
10/26/2015	14	60	0	0	Rain	34.95	64.83	1124.91
10/26/2015	16	30	1	0	Rain	45.00	71.69	1774.46
10/26/2015	17	30	1	1	Rain	34.82	72.95	1433.73
10/26/2015	19	60	0	0	Rain	16.84	49.41	1209.79
10/26/2015	20	30	1	0	Rain	53.06	170.41	1715.88
10/26/2015	21	60	0	0	Rain	29.86	83.25	1400.39
10/26/2015	22	30	1	1	Rain	81.41	68.20	1639.54
10/26/2015	23	30	0	1	Rain	36.71	41.21	1015.36

APPENDIX E

NITRATE EXPORTS FOR 2013 AND 2014